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An analysis of the effectiveness of a new watchstanding schedule for U.S. submariners

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THESIS

AN ANALYSIS OF THE EFFECTIVENESS OF A NEW WATCHSTANDING SCHEDULE FOR U.S. SUBMARINERS

by

Christopher M. Osborn

September 2004

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This study compares an experimental watchstanding schedule derived at Naval Submarine Medical Research Laboratory (NSMRL) with the schedule currently used onboard the submarine USS HENRY M. JACKSON (SSBN 730 GOLD). It analyzes subjective and objective data to determine if the new schedule is compatible in an operational submarine environment. This study reviews sleep and fatigue literature to emphasize important concepts needed to make schedule comparisons. Results from this study indicate a need exists among the U.S. submarine force to employ an operational schedule which provides more sleep and which is in better alignment with human circadian rhythms, thus improving cognitive effectiveness. One of the experimental schedules tested in this study yielded results similar to those of the existing submarine watchstanding schedule. This experimental schedule employed a validated model of human performance and fatigue to assess individual cognitive effectiveness. However, the results also indicate that the existing schedule is better suited in its accommodation of operational scheduling constraints which, in turn, allow watchstanders to receive more sleep. Recommendations address the need for the U.S. submarine force to continue to pursue a watchstanding schedule that provides better sleep while still accommodating operational constraints. Recommendations also address improvements in experiment implementation which can be integrated into future studies.

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EXECUTIVE SUMMARY

Research regarding submariner sleep dates as far back as 1949. Since then, operational demands have become more frequent for the U.S. submarine force and patrols are typically longer in duration. Advancing technology requires increased awareness and vigilance among the submarine's crew. As such, today's submarine force increasingly finds itself having to do more with less. Increased operational commitments coupled with declining submarine numbers since the end of the Cold War has placed added responsibility upon submarine officers and crews, which leads to the question: "How are these submariners sleeping?"

This study is part of a project sponsored by the Naval Submarine Medical Research Laboratory (NSMRL) at Groton, Connecticut. It is part of the final stage of a larger effort designed to determine if a new watchstanding schedule can improve circadian physiology, performance, and subjective appraisal of submariners while on board operational U.S. submarines. Specifically, this study investigates whether submariners will be more effective, acquire more sleep, or notice improvements in their own performance while on the new watchstanding schedule. Additionally, this study explores whether or not this new schedule is compatible in an operational submarine environment.

The submarine crew onboard the USS HENRY M. JACKSON (SSBN 730 GOLD) participated in the experiment. Subjective measures included demographic and exit surveys along with crew feedback. Objective measures included sleep data from wrist-worn activity monitors. These data were obtained while the crew operated on three different watchstanding schedules, two experimental schedules and one control schedule. The control schedule was the 18-hour watch schedule currently in use in the U.S. submarine fleet.

Results of this study demonstrated that there were no significant improvements in either cognitive effectiveness or amount of daily sleep while on the new schedule. Additionally, a majority of crew members did not like the new

schedule. The new schedule attempted to compress watch periods together in order to widen periods for contiguous sleep. However, little collateral work was completed during the compressed watch period, which meant unfinished work was carried over into the period set aside for sleep, defeating the intention of the new schedule's design. These results, taken together, demonstrated that the new schedule was not compatible in an operational submarine environment.

The results of this study illustrated that a need exists among the U.S. submarine force to improve upon current watchstanding schedules. A watchstanding schedule which allows for *both* better sleep hygiene *and* more time to complete required work should continue to be investigated. Such a schedule may increase tangible quantities for an individual, such as improved memory and cognitive effectiveness, but may also improve other, less tangible factors, such as crew quality of life, morale, and the retention of qualified personnel.

Although this at-sea trial of the experimental schedule was unsuccessful in improving submariner effectiveness and sleep hygiene, this study hopes to contribute to the sleep literature by highlighting the intricately related operational constraints imposed on U.S. submariners and the effects of various watchstanding schedules. The contributions of this study will hopefully allow future schedules to be better suited to the operational submarine environment.

I. INTRODUCTION

A. OVERVIEW

As is true with all of the services and their respective communities, today's submarine force increasingly finds itself having to do more with less. Increased operational commitments, coupled with declining numbers of submarines since the end of the Cold War, have placed additional responsibility and demands upon submarine officers and crews. As with any complex system requiring a human in-the-loop, this increased workload has come at a price: increased fatigue and reduced time for sleep and relaxation. According to a research proposal submitted to BUMED by Dyche and Carr (2001, p. 3) entitled *At Sea Trials of a New Submarine Watchstanding Schedule*,

> Sailors have been required to navigate their ships around the clock for centuries. Watchstanding schedules have by necessity required sailors to function effectively within atypical work and sleep patterns. Successful maritime watchstanding has been achieved by training, high standards of discipline, and relatively high manning levels (particularly in warships). Today, the combined factors of increasing sophistication of modern military vessels and initiatives to reduce manning levels have greatly increased the amount of information mariners have to process. The increased demand on individuals' alertness and vigilance is exacerbated by sustained continuous operations. Very little is known about the impact of different watchstanding schedules on the quality of life and operational performance of submariners. In other populations, such as shift workers, there is considerable evidence that human experience and performance are significantly affected when sleep and work patterns are abnormal.

As mentioned in this excerpt, and as illustrated by the large volume of related research literature, current information on the effects of fatigue on modern submarine operations is genuinely lacking. But although information and objective data regarding this critical area is lacking, interest is not. In fact, as a memorandum from the Commander of Submarine Group TWO to the Commanding Officer of the Office of Naval Research (2000) states:

> Sleep fatigue and its impact on performance is a subject of interest to the U.S. Navy, and, in particular, to the Submarine Force.

> Underway, the 18 hour work/sleep cycle on submarines may conflict with the human body's normal biological wake/sleep cycle and current evidence suggests that aligning the submarine watchstanding cycle with the human body's wake/sleep cycle may lower watchstanding fatigue and enhance individual performance.

This thesis, in conjunction with the Naval Submarine Medical Research Laboratory (NSMRL), was designed to address the need for research exploring submariner fatigue, and in addition, attempts to find ways to lower watchstander fatigue levels and improve individual performance and morale.

B. BACKGROUND

This thesis is one part of a three-part project sponsored by the Naval Submarine Medical Research Laboratory (NSMRL) at Groton, Connecticut. As part of the final stage of a larger effort, it is designed to determine if a new watchstanding schedule can significantly improve circadian physiology, performance, and submariner perceptions of their ability to perform their jobs while on board operational submarines. NSMRL's three-part project was designed to study: (1) approximately 350 surveys that assessed sleep quality and fatigue on active duty submariners; (2) a laboratory analysis of three separate and distinct watchstanding schedules on submariner physiology and performance; and (3) at-sea trials in support of laboratory findings. This thesis constitutes the latter tier, a test and evaluation of the laboratory product devised in the second tier aboard an operational U.S. submarine at sea (Miller, Dyche, Cardenas, & Carr, 2003).

C. OBJECTIVES

This thesis will compare the current 18 hour, three-section watchstanding schedule used by U.S. submarines (Stolgitis, 1969) to a laboratory-derived alternative schedule that more closely simulates a normal 24 hour cycle (Miller et al., 2003). Comparisons will be based on both subjective and objective observations, including surveys and crew feedback, in addition to more objective measures, such as sleep data obtained from activity monitors worn on the wrist.

D. PROBLEM STATEMENT

The hypotheses of this study are:

1. Submariners will be *more* effective on the experimental schedule,
2. Submariners will acquire *more* sleep on the experimental schedule,
3. Submariners will notice *improvements* in their own performance while on the experimental schedule,
4. The experimental watchstanding schedule will be compatible to an operational submarine schedule.

E. SCOPE, LIMITATIONS, AND ASSUMPTIONS

The ultimate goal of the study would be to extrapolate any significant findings to all crew members of the U.S. submarine force who stand three section watches. However, due to funding and time constraints, this experiment was limited to the crew of a single ballistic missile submarine (SSBN). An SSBN was chosen because it was the only platform available and also because an SSBN offers a fairly routine operational schedule in which to perform such an experiment. However, it should be acknowledged that by not conducting a similar study onboard a fast attack submarine (SSN), any findings reported here may not generalize to the entire submarine force.

Although the type of submarine used in this study generally implements a three section watch rotation, this procedure did not apply to all watch stations during the experimental period. Throughout the course of an underway period, more watchstanders would be training and would eventually become qualified for their respective watch stations. Therefore, these additional watchstanders would allow for more flexible watch rotations, including a modified three section watch which includes a “kick out”. A “kick out” is when a fourth watchstander, usually a senior crew member, stands watch during a certain period, such as from 1800 to 2400. This break provides a relief to the three-section watchstander who would normally have to stand that “kick out’s” watch. Thus, participant selection initially

included only three section watchstanders. However, as the experiment progressed, “kick outs” were unforeseeable and unavoidable, and may have slightly inflated sleep quantity.

Although collection of sleep data using polysomnograph (PSG) would have been ideal, given the field setting for the thesis, wrist-mounted avtivity monitors were used to obtain sleep information. Actigraphy is well established as a means to assess sleep-wake discrimination. Concordance rates for PSG and actigraphy have improved over the past decade from roughly 88% (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992) to approximately 94% (Jean-Louis, Kripke, Mason, Elliott, & Youngstedt, 2001) in laboratory based sleep studies. Actigraphy requires less technical training than polysomnography and is portable enough to use in the field. For these reasons, actigraphy was used to measure sleep which was the major measure of performance (MOP) for the thesis.

The Department of Defense (DoD) “Sleep, Activity, Fatigue, and Task Effectiveness” (SAFTE) model (see Chapter II.E), was implemented using a Microsoft® Windows program called the “Fatigue Avoidance Scheduling Tool”© (FAST). FAST© is typically used to predict and quantify crew cognitive effectiveness (Miller et al., 2003). Cognitive effectiveness equated to scores on a standardized psychomotor vigilance task (PVT), averaged by day, provides a validated measure of effectiveness (MOE) for submariners. Ideally, submarine crews should be effective during as much of the day as possible, given that they may be required to assist with emergencies at a moment’s notice. Both the strengths and weaknesses of the SAFTE model are described in more detail in Section II.E.

F. THESIS ORGANIZATION

Chapter II reviews pertinent literature on major concepts related to sleep deprivation and shift work. Chapter III discusses the methodology employed to conduct the experiment. Chapter IV describes the statistical approaches used in

the analysis. Finally, Chapter V concludes with results obtained from the analysis and provides recommendations for future research.

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II. LITERATURE REVIEW

A. OVERVIEW

Sleep research is an expanding field of study. Recent research and innovative techniques in recent years have increased our understanding of sleep and its importance in our lives. This section will introduce some important facts about sleep and the effects of sleep deprivation, in order to develop a better understanding and appreciation of the significance of this study. Section B describes the mechanisms of sleep and circadian rhythms. Section C discusses the effects of shift work on circadian rhythms. Section D outlines consequences of sleep deprivation on an individual's health and performance. Section E briefly explains the model this study uses to obtain cognitive effectiveness for schedule comparisons. Finally, Section F concludes by pointing out contributions from other work that relates to the study of submariner sleep.

B. SLEEP

Humans, like all higher organisms, require sleep in order to perform even the most basic functions. Sleep is the mechanism by which our body restores itself through the secretion of growth hormones and sleep may contribute to memory consolidation (National Sleep Foundation [NSF], 2004). When we awaken from a "good night's sleep", we feel "refreshed, alert, and ready to face daily challenges" (NSF, 2004). Unfortunately, in our increasingly fast-paced and busy society, a good night's sleep is becoming more and more of a luxury. In fact, a 2002 National Sleep Foundation (NSF) "Sleep in America" study found that roughly 74% of American adults experience a problem sleeping several nights a week (or more). Approximately 39% of adults get less than seven hours of sleep each weeknight, while 37% are so sleepy during the day that sleep loss can significantly interfere with daily activities. If the average American is experiencing problems obtaining enough sleep, one can only imagine the sleep problems experienced by U.S. Navy submarine crews. The sleep-related

problems typically found in the civilian population most likely extend to the U.S. military, particularly those engaged in 24-hour operations while underway.

The National Sleep Foundation suggests that a typical adult requires (on average) between 7 and 9 hours of sleep per day (National Sleep Foundation, 2004). Table 1 (below) presents the average sleep needs during an average human lifecycle. And although Table 1 presents "average" sleep needs, research suggests that sleep needs vary by individual (National Sleep Foundation, 2004). While some people may appear to "make do" with only 4 or 5 hours of sleep for several weeks or months with few negative effects on their cognitive, physical, and motor performance (although their mood and motivation may suffer), most people prefer and need 7 to 8 hours of continuous sleep per night (Giam, 1997). Younger individuals (many of whom operate submarines), require more sleep and a longer rest period to recover completely from additional physical stressors (Giam, 1997).

Infants/Babies*	0 – 2 months: 10.5 - 18.5 hours 2 - 12 months: 14 - 15 hours
Toddlers/Children*	12 -18 months: 13 - 15 hours 18 months - 3 years: 12 - 14 hours 3 - 5 years: 11 - 13 hours 5 -12 years: 9 - 11 hours
Adolescents	8.5 - 9.5 hours
Adults/Older Persons	On average: 7 - 9 hours

***Total time includes naps.

Table 1. Sleep Needs Over Our Life Cycle. (From: National Sleep Foundation, 2004).

1. Mechanism of Sleep

As a person sleeps, we undergo several predictable and measurable sleep stages, commonly referred to as Rapid Eye Movement (REM) sleep and non-REM (NREM) sleep. Roughly 75% of the sleep cycle is spent in four stages of non-REM sleep, which ranges from light dozing to deep sleep. The remaining

25% of the sleep cycle is spent in REM sleep where much dreaming occurs. A description of each stage of sleep, including physiological effects, is presented (below) in Table 1 (National Sleep Foundation, 2004). Notice that perhaps the most restorative stage of sleep is Stage 4, during which human growth hormone is released. As can be seen, REM sleep is also important for performance during the day, and research suggests that this stage may contribute to memory consolidation (National Sleep Foundation, 2004).

NREM: 75% of night	As we begin to fall asleep, we enter NREM, which is composed of Stages 1-4.
Stage 1	Light sleep; between being awake and entering sleep
Stage 2	Onset of sleep; becoming disengaged with the environment; breathing and heart rate are regular and body temperature goes down
Stage 3 & 4	Deepest and most restorative sleep; blood pressure drops; breathing slower; energy regained; and hormones are released for growth and development
REM: 25% of night	First occurs about 90 minutes after falling asleep and increases over later part of night; necessary for providing energy to brain and body; brain is active and dreams occur as eyes dart back and forth; bodies become immobile and relaxed; muscles shut down; breathing and heart rate may become irregular; important to daytime performance and may contribute to memory consolidation

Table 2. Explanation of Sleep Stages. (From: National Sleep Foundation, 2004).

An average sleep cycle, which consists of transitioning from stage 1 through stage 4 then back to stage 1 sleep, followed by REM sleep, typically requires approximately ninety minutes (Folkard & Barton, 1993). A typical 8-hour sleep cycle is shown in Figure 1 (below). The period of deepest sleep (stage 4), typically occurs within the first few hours of a sleep episode. As an individual progresses through the sleep cycle, REM episodes typically increase in length and non-REM sleep becomes shallower. This pattern is shown in Figure 1 by the

wider REM periods and more frequent occurrences of awakenings as the person approaches the end of the sleep period.

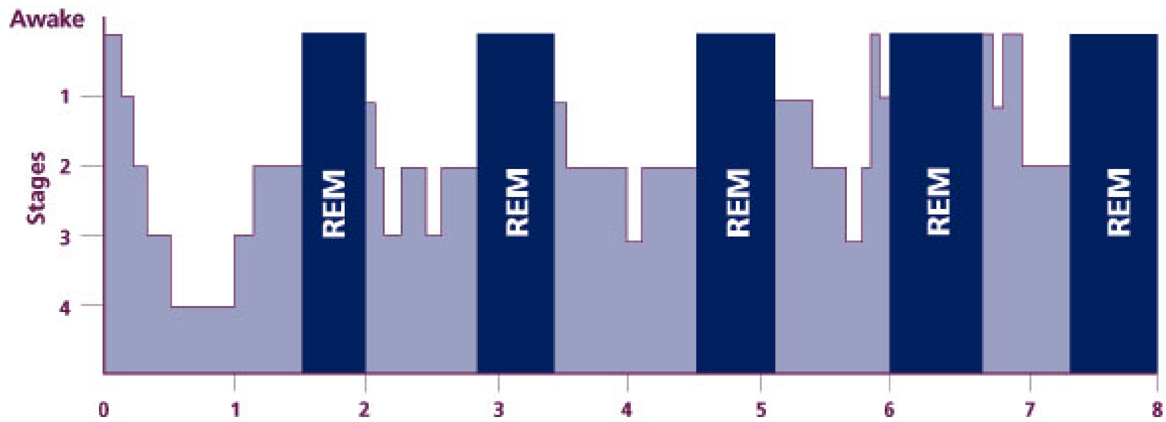

Figure 1. A Typical Sleep Cycle. (From: National Sleep Foundation, 2004).

2. Circadian Rhythms

Circadian rhythms, from the Latin "*circa dies*" which literally means "about a day", are those daily rhythms that govern much of our physiology and performance (Winget, DeRoshia, & Holley, 1985, p. 498). This internal body clock is located in the brain's hypothalamus and regulates daily variations in physiological processes, including sleep/wakefulness, body temperature, the release of hormones, as well as cognitive performance (Neri, Dinges, & Rosekind, 1997). Our mental alertness and cognitive performance closely corresponds to this daily fluctuation of our core body temperature (Neri et al., 1997). Thus, for a person on a typical sleep/wake schedule, maximum sleepiness occurs in the early morning hours, while a second period of increased sleepiness occurs in the midafternoon (Neri et al., 1997). Similarly, the maximum level of alertness typically occurs in the late morning and early evening. A simplified diagram of a typical circadian rhythm and its effect on alertness is presented in Figure 2.

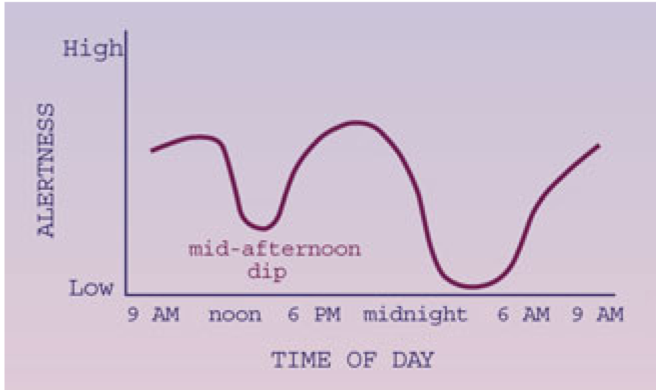

Figure 2. A Simple Diagram of Circadian Rhythm Affect on Alertness (From: National Sleep Foundation, 2004).

However, circadian rhythms do not always follow a 24-hour cycle. The human internal clock receives environmental clues, or *zeitgebers*, which include the daily alteration of light and dark and periodic social contact (or interactions such as meal times), which act as synchronizers (Winget et al., 1985,). In the absence of environmental time clues, human circadian rhythms will extend to a 25-hour cycle (Neri et al., 1997). This phenomenon helps to explain why it is easier for many individuals to stay up later (i.e., lengthening the day, a phase delay) rather than trying to go to sleep earlier (i.e., shortening the day, a phase advance). Whenever an individual experiences an abrupt phase delay or advance (such as changing time zones or shiftwork schedules such as encountered when working nights), problems can arise. Problems occur because it sometimes takes days or even weeks for the internal circadian clock to adapt physiologically to a new schedule (Neri et al., 1997).

C. THE EFFECTS OF ROTATING SHIFTS ON CIRCADIAN RHYTHMS

Rotating shifts are those in which a worker works on a particular shift for a period of time (e.g., day shift), then switches to a different shift (e.g., afternoon or evening) for a given period of time, and so on. A rotating shift schedule may employ either a forward or backward rotation: forward rotation moves clockwise,

from day to afternoon to night shift; conversely, a backward rotation moves counterclockwise, from day to night to afternoon shift (Rosa & Colligan, 1997).

Two factors which can affect one's adaptation to a rotating schedule are the speed and direction of the rotation (Rosa & Colligan, 1997). A fast rotation, which would change shifts every two days, does not allow sufficient time for individual circadian rhythms to adjust. Also, some researchers suggest that a forward rotation is better in helping a worker adjust to new sleep periods than a backward rotation (because it is typically easier to go to bed and wake up later than earlier) (Rosa & Colligan, 1997). But regardless of the type of rotation, both forward and backward rotating schedules can deleteriously affect worker performance (Rosa & Colligan, 1997).

Such forward and backward shift rotations, unfortunately, are regularly used in many military environments. For example, the three-section watchstanding schedule currently used in the U.S. submarine fleet is a rapid, backward rotating shift schedule with no "days off" between shifts. For example, a watchstander may have duty for 6 hours during the late morning hours (0600 to 1200), have 12 hours with no duty, and then stand the night shift, or mid watch (2400 to 0600) that night. An example of this kind of schedule, annotated as Schedule 3, is presented in on page 29. This schedule, in conjunction with an absence of photic cues (such as sunlight), can cause the circadian rhythms of certain crew members to desynchronize from the normal 24-hour daily schedule and synchronize to a period of about 24.5 hours (Miller et al., 2003), otherwise known as "circadian free run". Thus, some crew members experience a circadian phase lag that accumulates about 0.5 hours a day (compared to the ship's 24-hour schedule), which in turn can reportedly induce a feeling of illness or depression for these crew members (Miller et al., 2003).

D. CONSEQUENCES OF SLEEP DEPRIVATION

Sleep deprivation can be classified either as total sleep deprivation (in which an individual is denied sleep for *at least* 24 hours) or partial sleep

deprivation (which is any sleep less than the “usual” amount for the individual) (Giam, 1997). An illustration of how partial sleep deprivation can be cumulative, commonly referred to as sleep debt, is illustrated in Figure 3 (below). Belenky et al. (2002) conducted a study in which 66 volunteers were divided into four groups, which were then restricted in their amount of daily sleep for 7 days. Following this restriction, their reaction times were assessed using a psychomotor vigilance task (PVT). The PVT is extremely sensitive to sleep deprivation and is an indicator of “real world” task decrement (Dorian, Rogers, & Dinges, in press). As shown in Figure 3, the legend in the lower right corner represents daily hours of sleep for each of the different groups. As the downward trend in mean PVT responses indicate, for those with 7 hours or less of sleep per day, performance cumulatively decreases. In fact, chronic restriction of sleep to 6 hours or less per night produces cognitive performance deficits equivalent of up to 2 nights of total sleep deprivation (Van Dongen, Maislin, Mullington, & Dinges, 2003). Even more alarming is that the subjective sleepiness ratings (i.e., how each individual *rated* their perceived PVT performance), suggest that sleep deprived individuals are largely *unaware* of their increasing cognitive and physical performance deficits (Van Dongen et al., 2003).

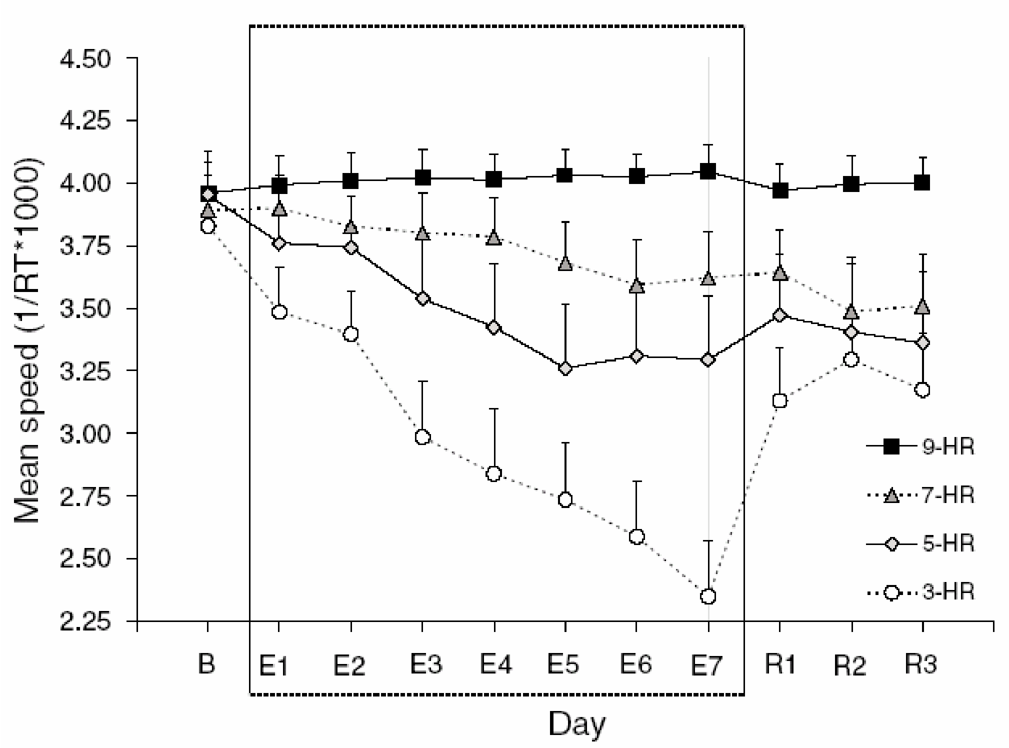

Figure 3. Mean Psychomotor Vigilance Task Speed (and Standard Error) Across Days as a Function of Time in Bed Group. (From: Belenky et al., 2002, p. 6).

People exhibit signs of sleep deprivation differently. Generally speaking, however, symptoms of sleep deprivation become more prevalent and persistent as sleep debt accumulates (Giam, 1997). Some major sleep deprivation symptoms mentioned by Giam (1997, pp. 91-92) include:

- Negative mood and motivational changes
- Impaired attention and alertness
- Short-term memory loss
- Variable and slower responses
- Visual/auditory hallucinations
- Failure to complete routines
- Impaired task performance

- Increased sensation of physical exertion
- Increase and subsequent cessation of bickering.

Furthermore, laboratory studies of sleep deprivation indicate that the most sensitive indicator of sleep deprivation is impaired task performance. For example, cognitive operations, such as logical reasoning, mathematical operations, short term memory, and decision making (Hursh & Bell, 2001), all suffer with increasing levels of sleep deprivation.

Dawson and Reid (1997) in an experimental comparison between the effects of alcohol ingestion and sleep deprivation, found similarities between the two in various measures of performance, including reduced motor skills, vigilance degradation, and increased response latency in a logical reasoning task. These studies suggest that, following 17-18 hours of sleep deprivation, motor and cognitive performance is equivalent to (or greater than) that of a person with a blood alcohol of concentration (BAC) of 0.05% (the legal driving limit in Australia). In addition, after 20-25 hours of wakefulness, performance impairment is equivalent to (or greater than) a BAC of 0.10% (the legal driving limit in many U.S. states).

In summary, the cumulative effects of sleep deprivation can impart performance degradations in both motor and cognitive functioning, and can lead to mental fatigue. Mental fatigue, as defined by Evans, Mackie, and Wylie (1991, p. 7) is unlike physical fatigue because it "is concerned with the individual's reduced capability for performing cognitive tasks in a timely and error-free manner." Mental fatigue impacts everyone, regardless of rank or rate, and can be "a strong disrupter of command level performance" (Hursh & Bell, 2001). If inadequate attention is given to opportunities for allowing the crew to get an adequate amount of sleep, then maintaining a high level of alertness will become difficult, with the result that the submarine crew's performance inevitably suffers.

E. THE SLEEP, ACTIVITY, FATIGUE, AND TASK EFFECTIVENESS MODEL (SAFTE)

The Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model, similar to the Walter Reed Army Institute of Research's (WRAIR) Sleep Performance Model (SPM), can be modified to serve several functions. The model uses sleep history data from individuals to estimate the existing cognitive capacity, or predicted effectiveness, of both the individual and the crew (Hursh et al., 2004). In addition, this model can be used to provide feedback to an individual who may be in need of sleep. It can also help in the selection of individuals or units for a particular operation or mission, and can also apply hypothetical or prospective work/sleep schedules which can be used to identify and alleviate potential performance problems. Lastly, this model can help in optimizing operational planning and management, or, conversely, provide a "weighting" function for individual performance in complex operational scenario models (Hursh et al., 2004). The method used in the SAFTE model was employed in this study to derive individual submariner effectiveness.

A conceptual schematic of the SAFTE model is presented in Figure 4. At the heart of the model is the "sleep reservoir", which maintains a balance of effective performance "units". Under fully rested, optimal conditions, a person has a finite, maximal capacity to perform (Hursh et al., 2004). When an individual is awake, the contents of this reservoir are slowly depleted according to a performance-use function, which specifies a linear decrease in the cognitive reservoir with each minute awake (Hursh & Bell, 2001). During sleep, the sleep reservoir is replenished by these units based on a sleep accumulation function which is responsive to an individual's sleep debt, or, more simply, the difference between the *current* level of the sleep reservoir and its maximum capacity, sleep intensity, and sleep quantity (Hursh & Bell, 2001). Sleep intensity is governed by both the time of day (circadian processes) and individual sleep debt (Hursh et al., 2004). Sleep quality, or conversely, sleep fragmentation, also affects the sleep accumulation function by introducing a penalty for interruptions in sleep. Performance effectiveness, which becomes the model's output, can be obtained

by summing three terms: the level of the sleep reservoir; the individual's circadian rhythm; and general stress effects (Hursh & Bell, 2001). The inertia component in Figure 4 represents presumed transient "post-sleep decay" of performance (Hursh et al., 2004).

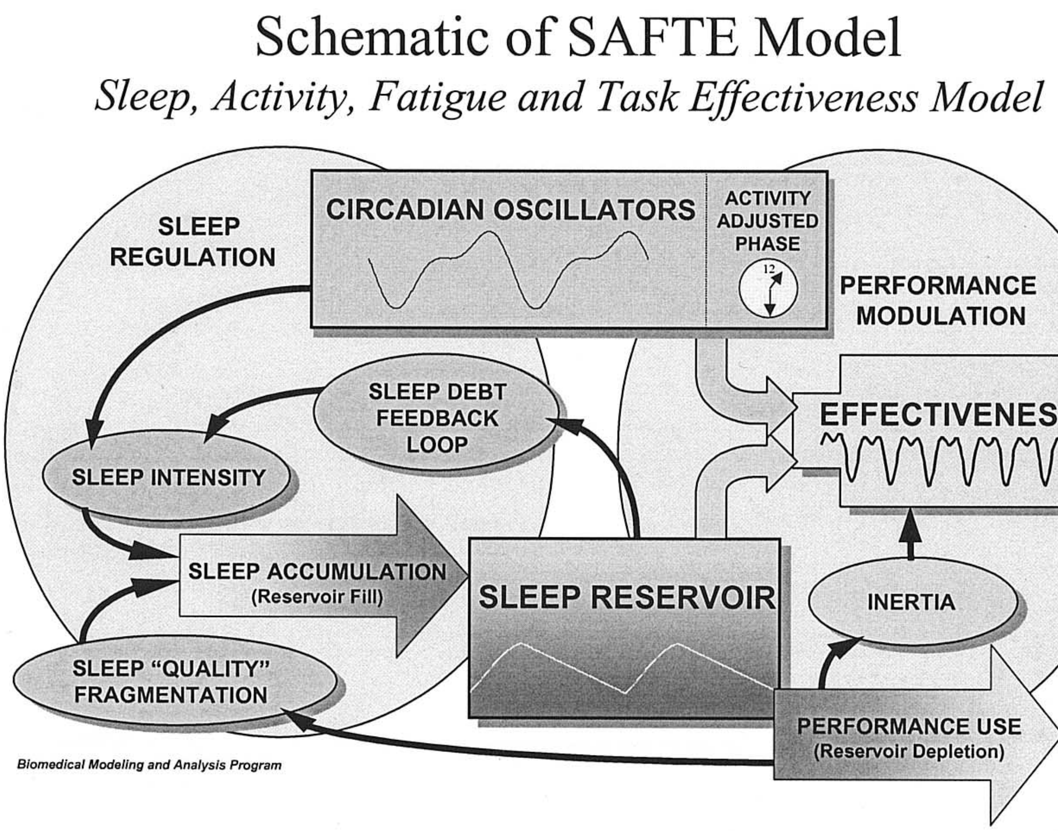

Figure 4. Block Diagram of SAFTE Model (From: Hursh et al., 2004, p. 2).

Nguyen (2002) identified several strengths of the SAFTE model. One strength identified is that the SAFTE model predicts the normal decline in sleep intensity over the sleep period and the normal equilibrium of performance under less than optimal schedules of sleep. In addition, this model integrates a multi-oscillator (i.e., the sum of two cosine waves) circadian process to predict circadian variations in sleep quality, limitations on performance under schedules that require sleep during the day, and sleep inertia that is proportional to sleep

debt. Additionally, this model takes into account changes in time zones and the effects of shiftwork (Nguyen, 2002).

The SAFTE model utilizes two sets of parameters that can be used to predict individual performance on a PVT, or the average cognitive throughput (correct answers per minute) of an individual (Hursh et al., 2004). Actual PVT speeds (obtained from a sleep dose-response study) were compared to those predicted by SAFTE/FAST©. The results can be seen in Figure 5. The SAFTE model predictions closely and significantly corresponded to actual PVT scores ($R^2 = 0.94$). The PVT has a high degree of reliability and validity, it is not dependent on individual aptitude, and because it can be administered repeatedly, it can be used to quantify the effects of sleep loss on an individual's neurobehavioral capabilities across a number of days (Dorian et al., in press). Thus, the SAFTE model, incorporated in FAST©, provides a useful prediction of "real-world" performance.

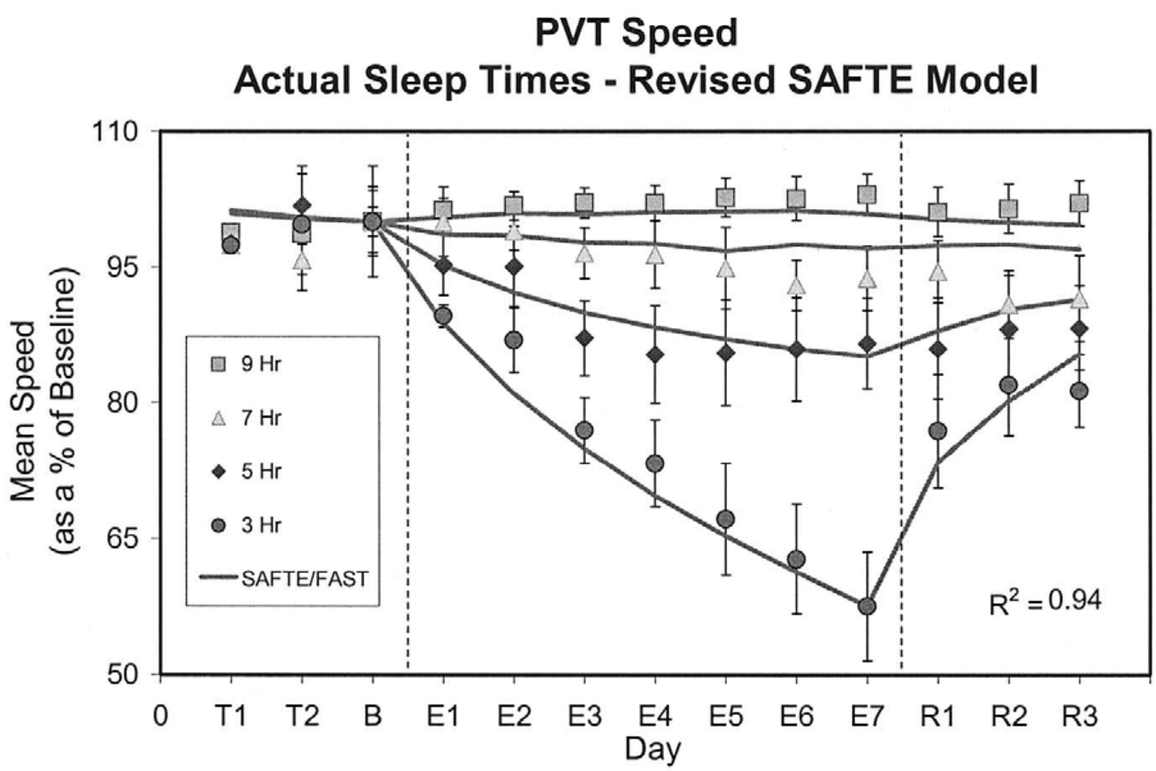

Figure 5. A Comparison of Actual PVT Speed to Predicted PVT Speed from a Sleep Dose Response Study. (From: Hursh et al., 2004, p. 8).

All models of sleep and performance, in fact, *any* model of sleep and performance, have shortcomings and limitations, particularly if a model is going to be used to make predictions. The SAFTE/FAST© model, as used in this study, has three major limitations. First, the model does not provide an estimate of group variance regarding the average performance prediction (Hursh et al., 2004), and only provides a point estimate for performance. Second, the model does not incorporate any individual difference parameters, such as age, that relate to full performance (Hursh et al., 2004). Last, and perhaps most importantly, the SAFTE model does not take into account the effects of pharmacological countermeasures, such as stimulants (e.g., caffeine) that extend performance, nor the effects of sedatives (e.g., clonazepam) or sleep agents (e.g., melatonin) to enhance sleep (Hursh et al., 2004). However, the impact of the first two limitations can be minimized by using a repeated measures design, as was done in this study. Because we could not assess the impact of any pharmacological agents, we presumed that the use of stimulants and sedatives were similar across all schedules.

F. RESEARCH ON SUBMARINER SLEEP

In 1949, renowned sleep researcher, Nathaniel Kleitman, conducted a survey and observed the sleep, work, and recreational habits of the submarine crew onboard the USS DOGFISH (SS 350) who stood the traditional 8 and 4 watch schedule (Kleitman, 1949). He believed that a submarine, as compared to other warships, presented the most conducive environment in which a maintained shift in the sleep-wakefulness cycle could be established. This belief was based on several factors, including: lack of reveille; rarely going to general quarters requiring the entire crew to be awake; daylight sleep was permitted; most work was done in artificial light; and watch and meal rotation was at the discretion of the Commanding Officer. However, Kleitman also realized that there were factors that hampered his work. These factors included the shore-type schedule of meals and recreation, and the inability of the men to achieve an uninterrupted sleep period of more than 7 hours duration (Kleitman, 1949). The

goal of his research was threefold: to suggest remedies for these unfavorable conditions, to find out how the crew of a submarine *actually* operated, and to determine whether misgivings concerning the adjustment of the men to a shifted sleep-wake cycle were justified (Kleitman, 1949).

One of Kleitman's results suggested that "…the routine of living on a typical submarine underway revealed an incomplete adjustment of the personnel to the requirement of an even degree of alertness during the 24-hour cycle of day and night and an absence of conditions conducive to such an adjustment" (Kleitman, 1949, p. 337). He suggested investigations be made of the variation in efficiency under the present schedule as well as under experimental modifications of a crew's typical routine.

Kleitman also went so far as to propose two watchstanding schedules that took into account meal times; one based on a 24-hour cycle and the other on a 12-hour cycle. Miller et al. (2003, p. 54) identified five objectives Kleitman used to construct these schedules:

- "Increased alertness and efficiency as a result of adjustment of working hours so that maximum body temperature might more easily coincide with them.
- Provision for 10-12 continuous hours off, during which long uninterrupted sleep may be secured.
- Watches of shorter duration, still providing for a total of eight hours' watch for each man.
- A schedule so nearly impartial that the watch periods might be fixed for each section throughout the cruise.
- A hot meal offered the men on each section before beginning their first watch of the day.
- A dinner hour so arranged as to make it possible for the men of all sections to eat their principal and best balanced meal of the day without disrupting sleep or breaking into a watch period (*ibid*.)."

Kleitman, in his research summary, identified two independent, though complementary, future studies that might contribute to good sleep and the well-being and efficiency of submarine personnel. One study suggested the establishment of a regular sleep-wakefulness cycle which conformed to the ship's routine. The other study suggested that the restful and restorative sleep could be achieved through the proper design and arrangement of sleeping equipment (e.g., making the bunks wider and longer).

In 1969, Stolgitis compared the common 4/8 hour work/rest cycle that was being used by the U.S. Navy surface fleet to the less common 6/12 hour work/rest cycle adopted by the U.S. nuclear submarine force. Specifically, he attempted to determine the relative capabilities of the two watch systems to provide the adequate sleep necessary for enabling the ship's crew to reliably and consistently perform their daily routines (Stolgitis, 1969). Stolgitis found the 6/12 system to be better for providing adequate sleep periods by establishing longer uninterrupted hours of sleep. However, Stolgitis's finding was based solely on an arithmetic comparison of contiguous sleep periods and not on empirical data. Therefore, the effects of circadian desynchrony were not taken into account when he concluded that the 6/12 cycle was better than the 4/8 cycle.

In 1999, efforts were made within the Royal Australian Navy (RAN) to examine stress in submariners and fatigue among Navy personnel (Chapman, 2001). Crew watch-keeping and rest cycles were examined onboard a RAN COLLINS-class diesel submarine, with the goal of establishing policy and guidelines for fatigue management. A submarine psychologist joined the crew of two COLLINS-class submarines to collect actigraphy data, saliva samples (used to assess melatonin levels), and both audio and visual recordings of the crew. The purpose of the study was to:

- Measure personnel sleep-wake cycles,
- Enable quantification of fatigue and sleep debt amongst personnel in an at-sea environment,

- Pilot test the research methodology in an at-sea environment aboard an operational submarine and determine the suitability of the methodology for further use during different types of submarine operations, and
- Obtain baseline data from which to develop a fatigue management policy tailored to the operation of the COLLINS-class platform.

Many recommendations, particularly within the areas of fatigue management, education, and policy development resulted from the study. However, the recommendations which were most pertinent to the scope of the current study were in the area of policy development. Chapman recommended:

> …that a comprehensive fatigue management policy be developed in collaboration with an industry expert that addresses the following:
>
> a. watch systems and scheduling, sleep management and strategic napping in the COLLINS-class environment;
>
> b. development, practice and adherence to sleep management plans for personnel;
>
> c. exploring the inclusion of personnel redundancies for those departments experiencing high cognitive load (to assist in more effective fatigue management); and
>
> d. modification of task rotation and time of completion to measure cognitive workload and minimise effects of sleep loss (2001, p. 4).

In 2001, Blassingame analyzed 143 surveys obtained from enlisted U.S. submariners with at least one year of operational experience onboard a submarine in order to gain insight into their sleeping habits (Blassingame, 2001). The survey was designed by Naval Submarine Medical Research Laboratory (NSMRL), Groton, CT, to determine whether there were differences in the reported amount of sleep between sailors in four different operational environments: at sea, in port, on shore duty, and on leave.

Blassingame's analysis concluded that there were discernable differences in the quality and quantity of sleep between the different environments. Of the four operational conditions evaluated, the "at sea" condition was the most

different from all other conditions (Blassingame, 2001). Submariners reported getting less sleep while “at sea” than in the other conditions and had much less control over the amount of sleep they got when deployed.

In 2002, Gamboa analyzed survey responses from 258 submariners using a combination of Blassingame’s survey data and additional survey responses obtained onboard the USS CONNECTICUT (SSN 22) (Gamboa, 2002). The goal of his research was to determine if a shift in working environment (from shore duty to sea duty) had an effect on enlisted submariner sleep patterns. Additionally, Gamboa attempted to determine whether career longevity had an effect on self-reported optimal sleep duration.

Gamboa’s research (2002) revealed that sleep patterns were reported to be more disturbed in the underway environment. One interesting finding was that crew members reported needing *fewer* hours of sleep to function optimally in the underway working environment then when they were in a shore duty working environment. As was discussed in Section D, sleep deprived individuals are largely unaware of the increasing cognitive deficits (Van Dongen et al., 2003). In fact, Gamboa (2002, p. 2) identified that:

> The individual warfighter may, over time, subsequently perceive a need for fewer hours of sleep to function at that minimum level. This behavioral change that corresponds to a "perceived" physiological conditioning illustrates cognitive dissonance reduction theory, which states that an individual will attempt to remedy a perceived “dissonance” or “disconnect” between two or more beliefs. In this case, the person is attempting to reduce the perceived dissonance between the environment, that of continual sleep deprivation, which tends to be the norm, and the belief that the individual needs a certain number of hours to function optimally.

Festinger’s cognitive dissonance reduction theory (as cited in Gamboa, 2002) helped to explain this phenomenon. In addition, Gamboa’s results indicated that rank, time in service, sea time, and self-reported optimal sleep duration had an effect on respondent sleep patterns. For example, those submariners with more experience reported that they needed less sleep to function while underway. Festinger’s cognitive dissonance reduction theory may

help explain why the current 6/12 watchstanding schedule has, until recent years, received little attention within the sleep research community.

An experiment was conducted in 2001 at the Chronobiology and Sleep Lab (CASL) of the Warfighter Fatigue Countermeasures Research and Development Program, Air Force Research Laboratory, Brooks AFB TX (Miller, Dyche, Cardenas, & Carr, 2003). Nine male enlisted submariners voluntarily participated as research subjects. The participants spent three 8-day periods in the CASL and were exposed to three different watchstanding schedules: 1) the 18-hour watch schedule currently in use by the U.S. submarine fleet, 2) the traditional maritime watch schedule used by some Coast Guard cutter crew members, and 3) the alternative watch schedule analyzed in this study (refer to on page 29).

Five hypotheses were tested in this experiment. Conclusions formulated after the completion of the experiment supported the following hypotheses (Miller et al., 2003):

- 24-hour work-rest cycles were in better physiological alignment with circadian rhythms and produced better performance than did an 18-hour work-rest cycle.
- Given the same average amount of time in bed and average time spent on watch per 24 hours, both sleep quality and sleep quantity were worse in an 18-hour work-rest schedule than in 24-hour work-rest cycles.
- Given the same average amount of time in bed and average time spent on watch per 24 hours, both sleep quality and sleep quantity were worse in a standard maritime work-rest schedule than in an alternative 24-hour work-rest cycle.
- And lastly, given the same average amount of time in bed and average time spent on watch per 24 hours, individual mood was worse in a

standard maritime work-rest schedule than in an alternative 24-hour work-rest cycle.

After combining the results of the study with information available in research literature, Miller et al. provided watchstanding schedules to be tested in at-sea trials. The schedule(s) which were recommended depended upon its function, such as lengthening the watch to achieve more time off watch or to accommodate 24-hour operations in a geographically-confined, limited-crew number situation, etc.

As illustrated by this literature review, current information on the effects of fatigue on modern submarine operations is seriously lacking. This thesis is designed to empirically assess the utility of a new watchstanding schedule. The compressed 6-hour watchstanding schedule, referred to by Miller et al. (2003) as the “A Schedule”, is the schedule which was used in the at-sea trial implementation.

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III. METHOD

This section discusses the experimental design, participants, apparatus, and procedure. Data formatting concludes this section and is intended to provide a smooth transition into the next section which discusses analytical results.

A. EXPERIMENTAL DESIGN

Two SSN submarines and two SSBN submarines were originally going to be used for the at-sea trials portion of this experiment as outlined in a research proposal by NSMRL (Dyche & Carr, 2001). Due to funding constraints and submarine availability, it was decided that one SSBN would serve as both the control and experimental group. The experimental design therefore became a repeated-measures design.

The Commanding Officer of the USS HENRY M. JACKSON (SSBN 730 GOLD) volunteered his ship for the experiment. LT Chris Duplessis, M.D., an Undersea Medical Officer (UMO) from NSMRL, joined the submarine's crew for approximately one month to conduct the experiment. The experiment started October 29, 2003 and lasted until December 2, 2003.

Although this study was originally intended to assess two watchstanding schedules (one experimental and one regular schedule), the experimental schedule was modified during the experiment in response to command element suggestions that modifying the experimental schedule would better coincide with the ship's schedule. Instead of the 24-hour off period occurring from noon to noon, it was suggested (and implemented) that a modified experimental schedule have off from midnight to midnight. Because of this change, a comparison of the three watchstanding schedules ultimately tested is shown in . Blackened boxes indicate on-watch periods while white boxes indicate off-watch periods.

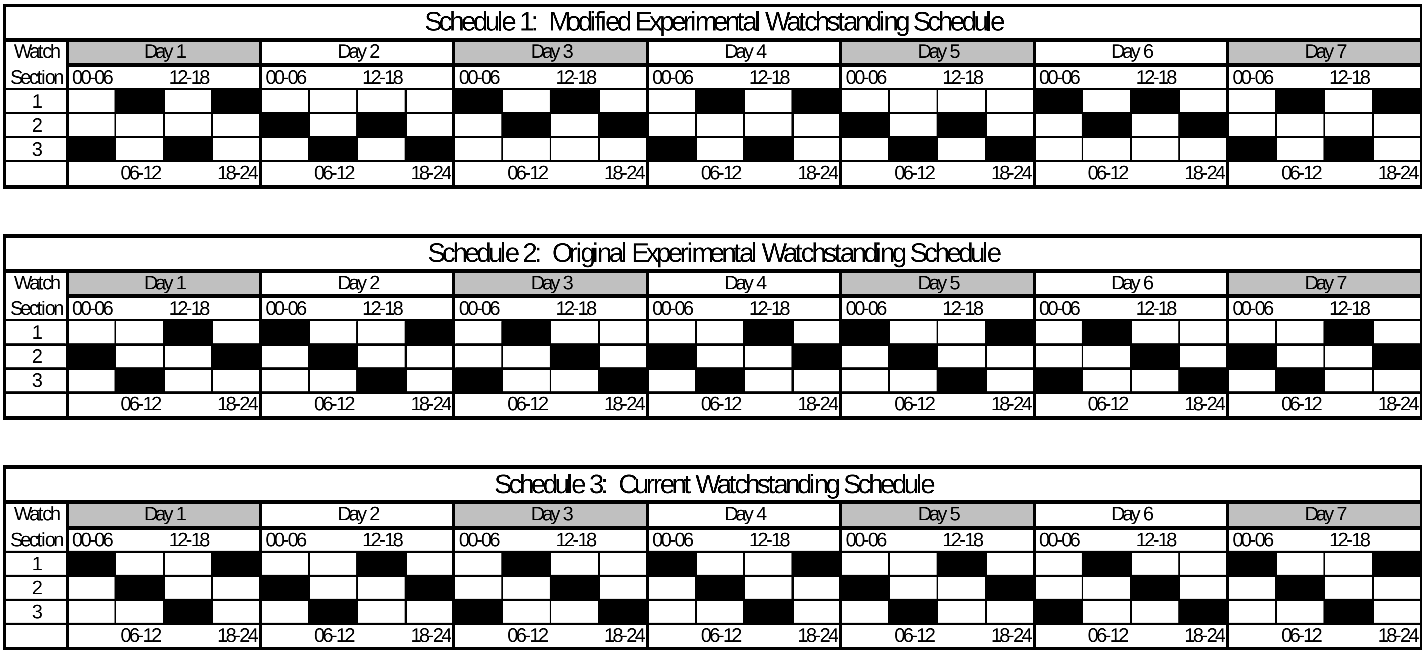

Figure 6. Three Watchstanding Schedules Used in the Study.

Schedule 1, the *modified* experimental schedule, was tested for 14 days. Schedule 2, the *original* experimental watchstanding schedule, was tested for 6 days. Schedule 3, the *current* submarine watchstanding schedule being used in the fleet, was tested for 12 days. The experiment lasted a total of 32 days.

B. PARTICIPANTS

Participants were selected using four criteria. First, each participant would normally stand a three-section watch because the experimental schedule was designed for a three-section watch. Second, to minimize potentially confounding variables (such as extra time being spent on qualifications), participants should already be qualified in submarines. Third, to obtain a representative sample of the crew on an 18-hour rotating schedule, each participant could not be a department head or a member of the command suite (CO, XO, COB, or EDMC). Lastly, the proportion of job ratings needed to be maintained as closely as possible to the actual crew composition. For example, if Sonar Technicians comprised 10% of the crew, then roughly 10% of the 40 participants wearing

actigraphy monitors would need to be Sonar Technicians. Once participants were screened using these restrictions, they were selected at random to be participants and informed consent was obtained.

Participants for the at-sea trials portion of the experiment consisted of male volunteer crewmembers of the ballistic missile submarine USS HENRY M. JACKSON (SSBN 730 GOLD). Participant ages ranged from 20 to 37 years, with the average age being 25.6 years, and they did not receive payment for their participation.

C. APPARATUS

1. Actigraphy

a. Wrist Activity Monitors (WAMs)

Actigraphy was originally developed to objectively measure and quantify sleep prior to the development of polysomnographic techniques. Actigraphs (see Figure 7) are watch-like devices manufactured by Precision Control Design, Inc. which identify and store slight body movements using an accelerometer. These devices, commonly referred to as wrist activity monitors or WAMs, can (roughly) discern whether or not the individual is sleeping by using approximations of the Cole-Kripke sleep-scoring algorithm (Cole et al., 1992) and the WRAIR Sleep Performance Prediction Model (SPM) (Redmond & Hegge, 1985).

Figure 7. A Typical SleepWatch-O 0.1 Actigraph.

The SleepWatch-O Actigraph has the ability to collect data in five modes: 1) Zero Crossing Mode (ZCM), 2) Time Above Threshold (TAT), 3) Dual (ZCM and TAT), 4) Proportional Integral Mode (PIM), and 5) PIM/ZCM/TAT (PZT). The ZCM mode measures the frequency of movement, the TAT measures the time spent in motion or duty cycle, and the PIM measures accumulative activity level or vigor of motion (Nguyen, 2002). The PZT was used in the data collected for this experiment. However, only data from the ZCM mode using one minute epochs were used in the analyses. WAMs were initialized and, following data collection, downloaded to a personal computer using an Ambulatory Monitoring, Inc., OS2K Reader interface.

b. AMI ACT Millenium© Beta Version 3.5.13.2

ACT Millennium© software, developed by Ambulatory Monitoring, Inc., was used to initialize and download actigraphy data. Figure 8 presents an example of how actigraphy data appear once downloaded.

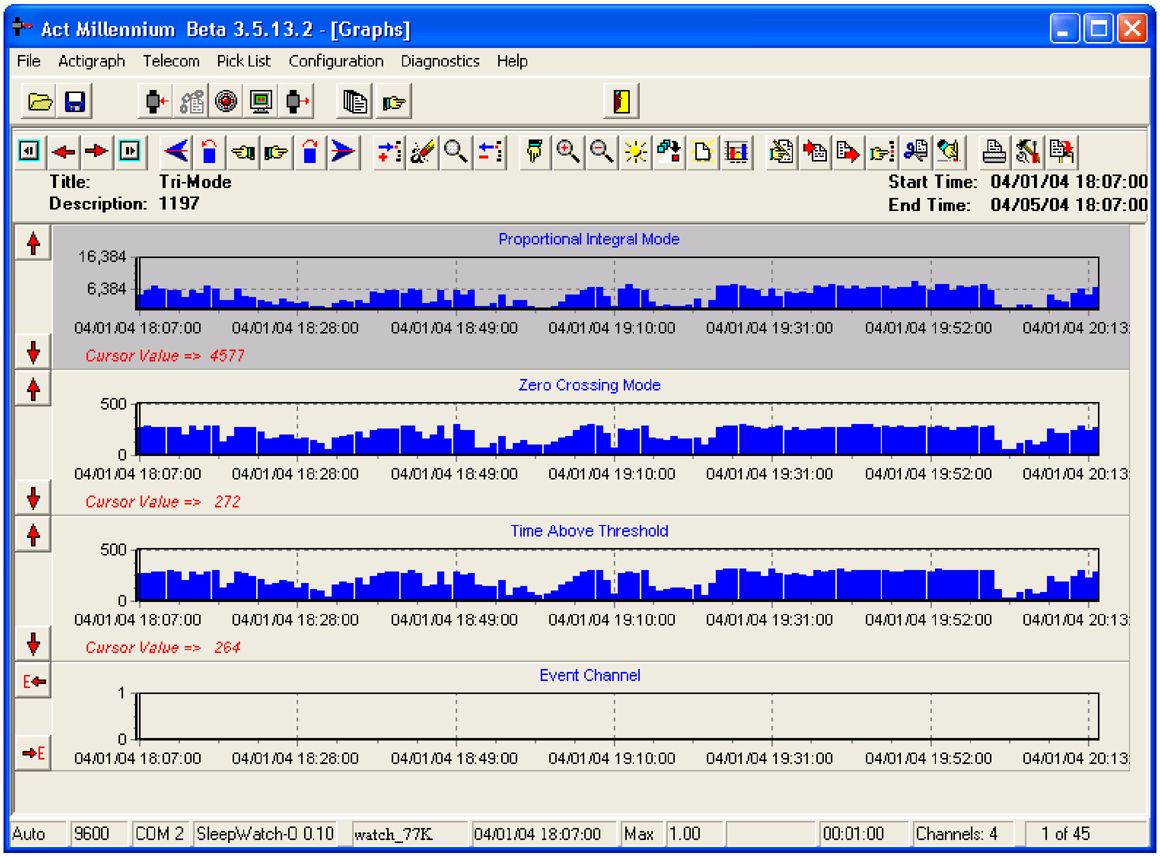

Figure 8. Sample Screen of ACT Millenium© Software.

c. Action-W 2© Version 2.4.20

Action-W 2©, a software program created by AMI, provides a Graphical User Interface (GUI) which enables a user to edit actigraphy data files. These files, created by the ACT Millenium© program, were used to obtain summary statistics for sleep and wake episodes. This editing capability proved useful when the actigraphy coded very low activity periods as sleep (when it was clearly not warranted). For example, if a wearer removed the watch, the sleep algorithm coded the period as sleep even though the individual was awake, thus introducing inaccurate data into subsequent effectiveness calculations. Figure 9 demonstrates such a scenario. Activity, denoted by vertical black bars, is sorted into rows representing 24 hour periods. Horizontal red lines placed beneath the activity represent periods coded as sleep. The orange circle on Figure 9 illustrates a period when the wrist activity monitor (WAM) was removed, and was

therefore originally coded as a sleep period. Because the individual was awake during this time, the period was manually coded as a wake period, thereby removing an inaccurate horizontal red "sleep bar" beneath the data.

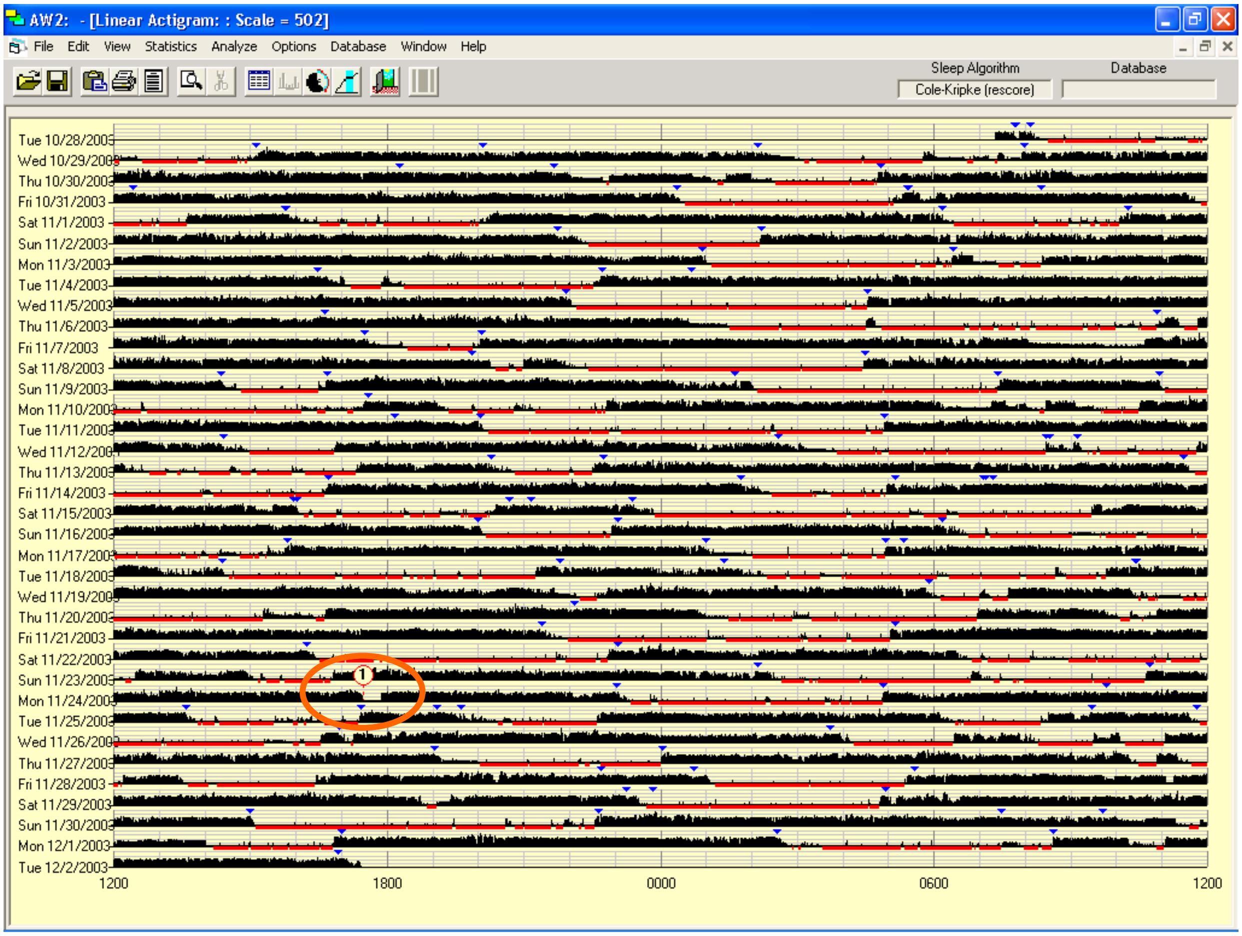

Figure 9. Sample Screen of Action-W 2 © Software. Circled period indicates a period when the wrist activity monitor was removed and had to be manually coded as wakefulness.

d. Sleep Logs

A sleep log was used to record significant events (such as removing the WAM, laying down for sleep, waking up, etc.). These logs provided the ability to cross-reference activity levels during data cleaning. Sleep logs consisted of a participant number, date, time of event, and the event. Entries were color-coded for ease of reference. White lettering indicates a recorded event. Figure 10 is an example of one page of the sleep log.

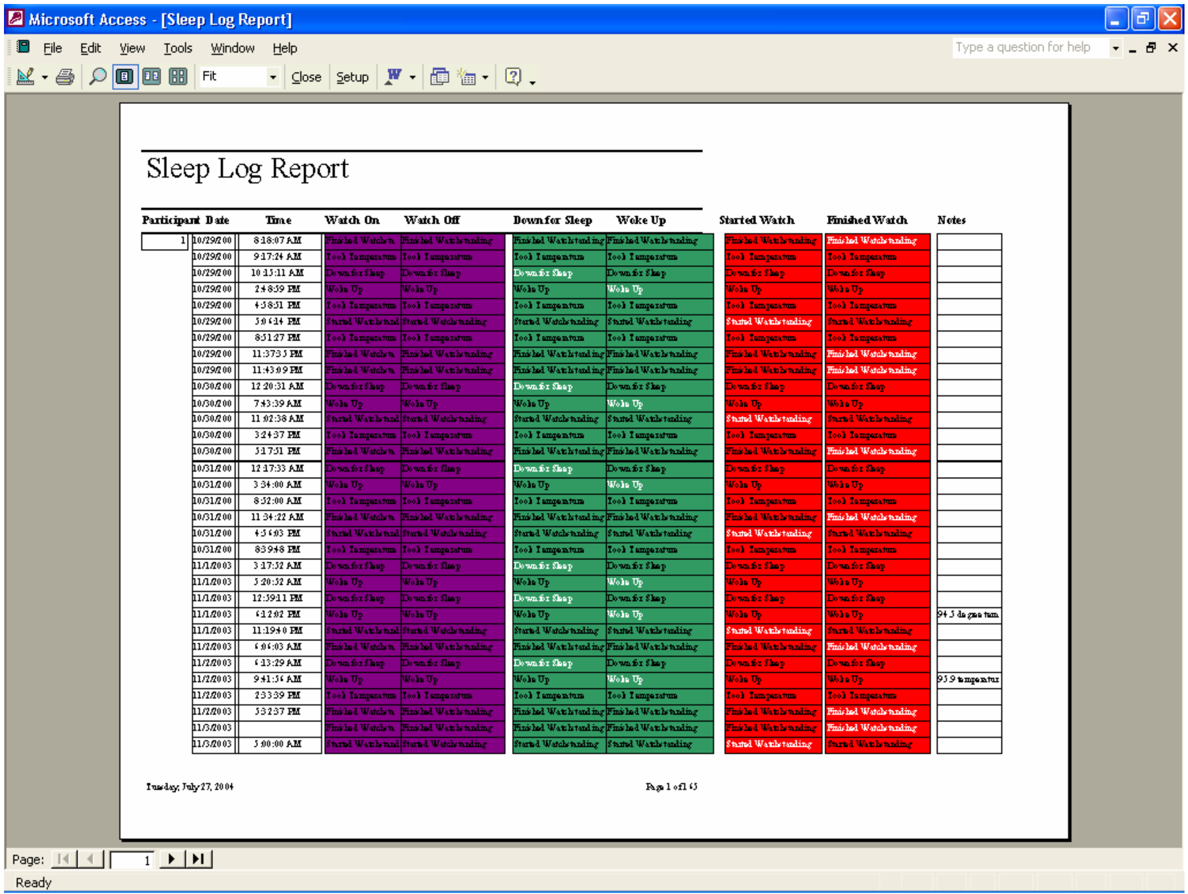

Figure 10. A Sample Page of the Sleep Log Report.

Each participant was also issued a Handspring ® Treo Personal Digital Assistant (PDA) so they could track significant events including logs of their sleep. These sleep logs were created on a PDA database program called HanDBase V3.0h by DDH Software, Inc. Data could then be downloaded from the PDAs and transferred directly into Microsoft ® Access 2002 for cross-reference.

e. Fatigue Avoidance Scheduling Tool (FAST©) Beta Version 0.9.57

The Fatigue Avoidance Scheduling Tool © (FAST) was created for Science Applications International Corporation (SAIC) and NTI, Inc. The FAST© program utilizes the human sleep and performance SAFTE model (see page 16)

which serves as a fatigue avoidance decision aid for operational planning. This model has been used extensively by the United States Air Force in aircrew mission planning. An example of FAST's graphical display is presented in Figure 11.

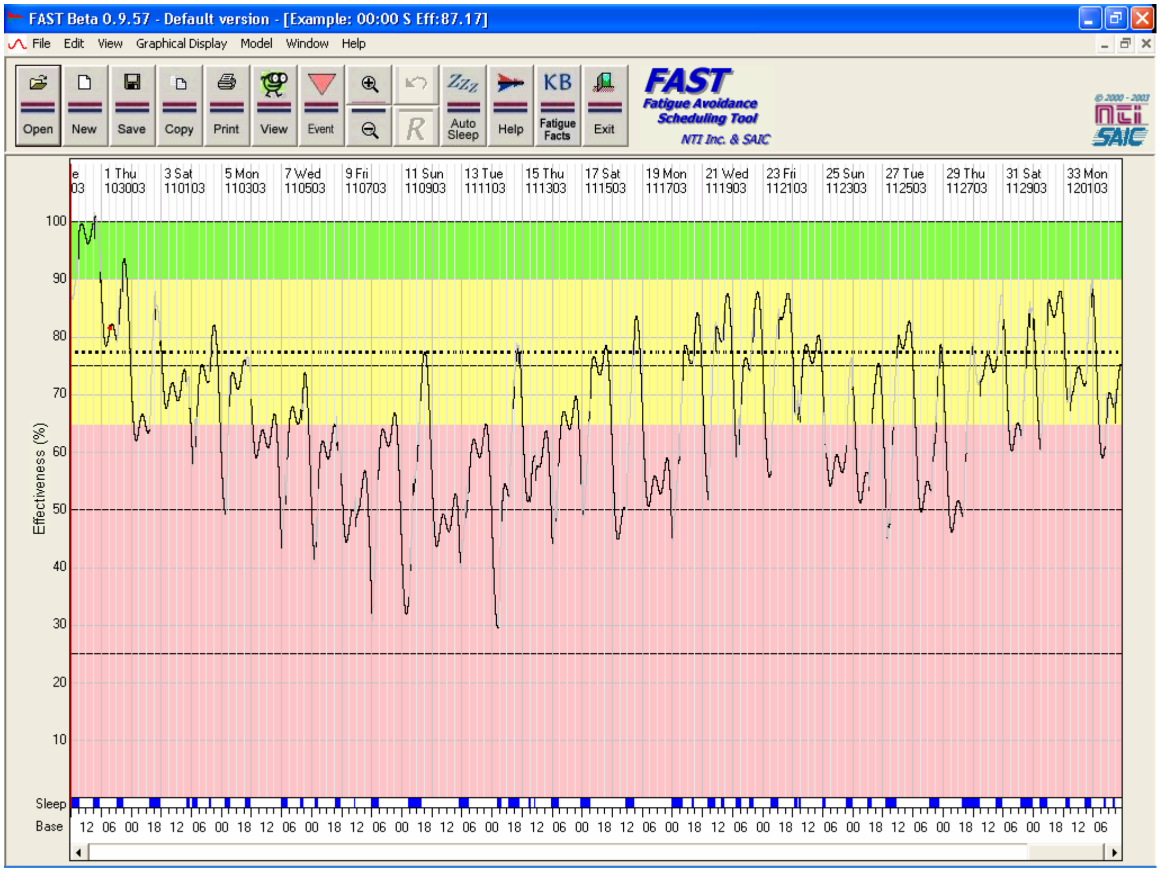

Figure 11. An Example of FAST's Graphical Display of Daily Effectiveness.

2. Surveys

The demographic and exit surveys were designed by a group of four Naval Postgraduate School students prior to the at-sea trials portion of the experiment. Both surveys used Microsoft ® Access 2002 and were designed to be taken by the crew on the ship's computer network (LAN). Survey questions were modified so that participants answered questions regarding the schedule they were on at the time of the assessment.

a. Demographic Survey

The goal of the demographic survey was to collect basic information such as rank or rate, age, weight, height, department, medication(s), etc. Appendix A contains a copy of the demographic survey.

b. Exit Survey

The goal of the exit survey was threefold:

1. Assess the submarine crew's sleep quality and fatigue on each watchstanding schedule,
2. Determine if the experimental watchstanding schedule was operationally viable, and
3. Assess the individual's overall impression of the crew's performance and schedule viability.

D. PROCEDURE

1. Actigraphy

During the experiment, 41 participants were issued wrist activity monitors (WAMs). Because of equipment failures and other problems, only 29 of the 41 participants had contiguous actigraphy data covering the entire experimental period. The data of these 29 participants were used in the analysis. Of the 29 participants, 11 were from the Engineering Department, 9 were from the Navigation Department, 7 were from the Weapons Department, and 2 were Junior Officers.

2. Surveys

Both the demographic and exits surveys were posted on the ship's LAN and were available to be taken by the entire crew during the latter portion of the experiment. Each crew member was assigned a participant number to ensure anonymity. Overall, there were 107 respondents to the demographic survey and 134 respondents to the exit survey.

Unfortunately, problems arose with the demographic and exit surveys during the experiment. Because the surveys were designed with comparative analysis in mind, they were meant to be taken near the end of each schedule implementation during the experiment. To eliminate the need for each participant to take the exit survey three separate times, both surveys were posted on the ship's LAN with two days left on Schedule 2. Since Schedule 1 had already been tested, Schedule 1 and Schedule 2 were both treated as a single experimental schedule. Unfortunately, the majority of the surveys were completed with only three days left before the end of Schedule 3. This created confusion among the participants who took the survey on the LAN, because they were not sure which schedule the survey was referring to since they already had completed three schedules. Unfortunately, this confusion appeared to be reflected in a number of survey responses. Figure 12 illustrates the misleading phrasing.

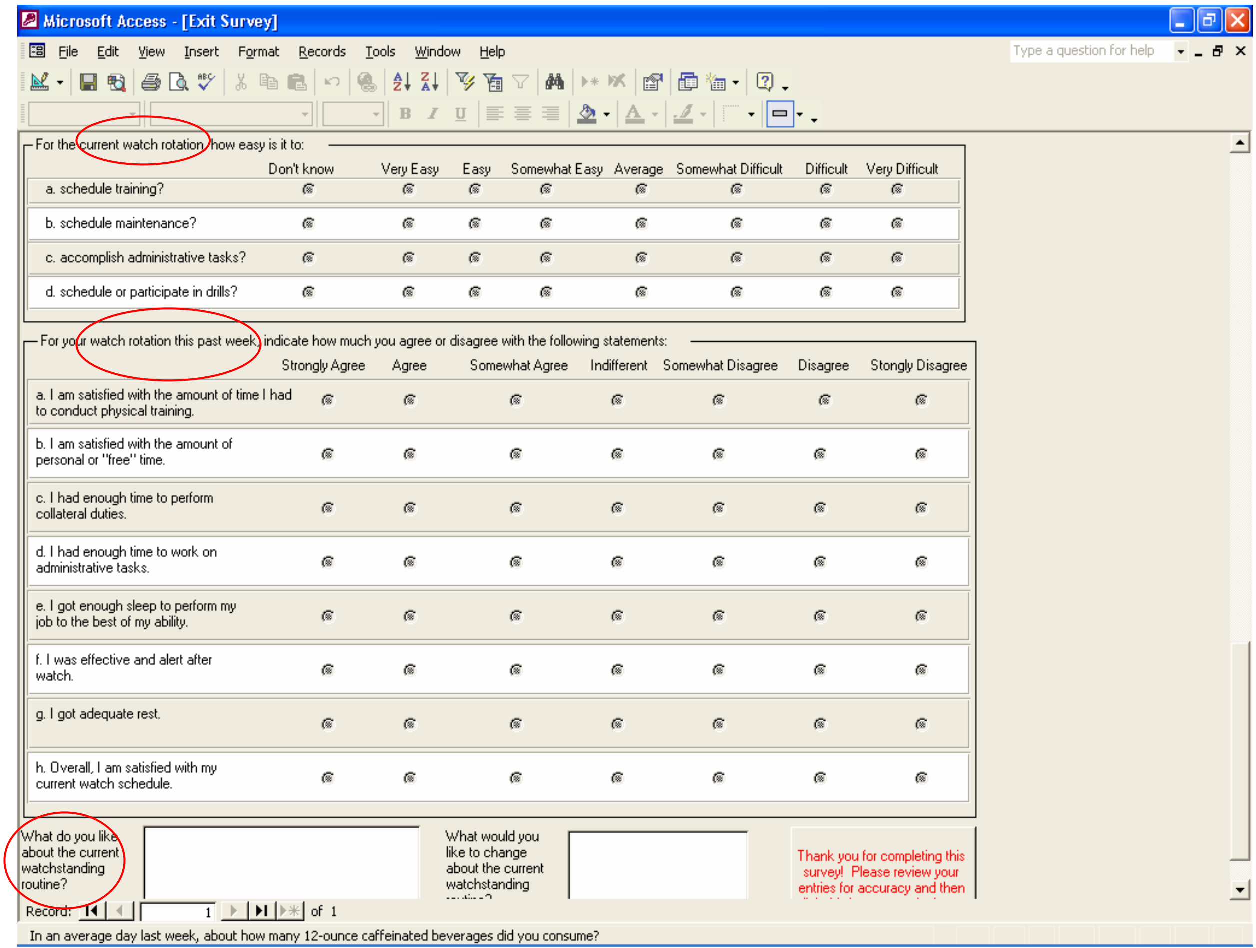

Figure 12. Illustration of Misleading Exit Survey Phrasing.

In an attempt to alleviate some of this confusion and to maximize survey participation, participants were directed to answer the surveys *as if* they were on the experimental schedule and to use the final two open-ended questions to describe both what they liked and disliked about the experimental schedule. Despite these efforts, there were still survey responses which indicated the participant answered the questions according to the schedule they were currently on (in Figure 12, this was Schedule 3).

3. Extraneous Data

Other data were collected but not used in this analysis, specifically those items necessary to analyze circadian rhythm desynchrony. Circadian markers,

such as melatonin (obtained via saliva samples), and body temperature readings (using oral thermometers), were collected from 10 participants. In addition, an ARES performance battery, similar in function to the Psychomotor Vigilance Test (PVT), was undertaken by the participants wearing WAMs. These data were not analyzed for this thesis. Questions regarding this data may be directed to LT Chris Duplessis, M.D., NSMRL, Groton, Connecticut, Duplessis@nsmrl.navy.mil.

E. DATA ENTRY AND FORMATTING

1. Effectiveness

Once the actigraphy data were edited using Action-W 2©, each file was saved as an “Epoch by Epoch” file (.ebe) for input into FAST©. Before the data were analyzed by FAST©, a schedule template was created to reflect the study duration of 35 days (October 29, 2003 to December 2, 2003), and was used in the analysis of each participant’s data. Automatic phase shift, a mathematical model used by FAST©, automatically adjusts the acrophase of the 24-hour rhythm based on the individual’s sleep schedule. Location information was not used in the schedule because the enclosed submarine environment rendered it unnecessary due to the lack of *zeitgebers*, or environmental clues such as daylight and nighttime. One precondition that was assumed in the FAST© analysis was that participants had slept from 2200 until 0600 for three consecutive days of preconditioning prior to the ship getting underway.

Once the FAST© schedule template was created, the “Epoch by Epoch” actigraphy file was imported into FAST© in order to calculate predicted daily effectiveness. Because of the large number of participants who appeared to experience fragmented sleep (evidenced by the large number of sleep intervals seen in FAST’s summary data tables), it became necessary to reduce FAST’s sleep interval resolution. Dr. Steve Hursh, the developer of the FAST model, was consulted, and he suggested editing the schedule’s grid. By assigning a 15-minute block during which the participant was awake, and designating it as work, the model recalculated effectiveness by incorporating the binary sleep indicator into 15-minute blocks vice 1 minute blocks. For example, a participant’s data

would have to be coded as sleep for at least 7.5 minutes of every 15-minute period for the FAST© model to have scored the entire 15-minute interval as sleep. Forcing FAST© to recalculate effectiveness in this manner acted to smooth the data for fragmented sleepers, and in most cases, daily effectiveness in the FAST model noticeably increased.

Once data smoothing was complete, FAST© effectiveness data (taken from the tabular view) was copied and pasted into Excel. Using a separate worksheet for each participant, effectiveness was averaged by day and compiled into a data summary worksheet which incorporated all of the participants' data. This data summary was then exported into S-Plus© as a data frame structure for analysis.

2. Sleep Quantity

Sleep quantity was obtained using the "edited AMI data file" created in Action-W 2©. Clicking on "Statistics" on the toolbar yielded summary statistics, including daily sleep minutes, percent sleep, longest sleep episode, etc. This tabular data set was saved as a text file, imported into Microsoft ® Excel 2000 (to allow daily sleep minutes to be arranged as an S-Plus© data frame), and then imported into S-Plus 2000© for subsequent analysis.

3. Surveys

Although 85 exit surveys were completed on the ship's LAN, another 49 had to be manually transferred into Microsoft ® Access 2002. Once this transfer was complete, surveys were exported from Microsoft ® Access 2002 to Microsoft ® Excel 2002. Blank entries were coded as "NA" and responses such as "I don't know" or the equivalent were coded as "DK". Multiple-choice and Likert scale questions were coded as ordinal (based on question phrasing), with lower numbers representing negative answers. Because of the problems with the survey (as previously mentioned in Section D.2 of this chapter), a new column was created which represented whether or not it was possible to distinguish

whether the respondent favored an experimental watch schedule based on the open-ended question responses. An additional column was created that represented whether or not conflicts existed between the “open-ended” and multiple-choice responses. For example, a respondent would speak of the experimental schedule unfavorably in the “open-ended” questions, but his multiple-choice responses would indicate otherwise. Finally, the Excel file was imported into S-Plus© for analysis as described in Chapter IV.B.

IV. RESULTS AND ANALYSIS

A. OVERVIEW

This section outlines the statistical analysis performed on the survey and actigraphy data described in Chapter III (Section D). Section B (below) summarizes the findings of the analysis, while Section C gives the details of the analysis of the actigraphy and survey data.

Actigraphy and FAST© data were used to test hypothesis 1, which states that submariners will be more effective on the experimental schedule. Actigraphy data were also used to test hypothesis 2, which states that submariners would obtain more sleep on the experimental schedule. Survey data and direct crew feedback were used to test both hypothesis 3 (which states that submariners would notice improvements in individual performance while on the experimental schedule), and hypothesis 4, (which states that the experimental watchstanding schedule would be compatible to an operational submarine environment).

As mentioned previously in Chapter 0, schedule names are defined in the order they were implemented in the experiment. Thus, Schedule 1 refers to the *modified* experimental schedule in which the 24-hour off period starts at midnight every 3 days. Schedule 2 refers to the *original* experimental schedule in which the 24-hour off period starts at noon every 3 days. And lastly, Schedule 3 is the *normal* 18-hour rotational watchstanding schedule currently used by U.S. submarine crews.

B. RESULTS

1. Hypothesis 1: Submariners Will be More Effective on the Experimental Schedule

To test hypothesis 1, a linear multiple regression model was first used with FAST© effectiveness data to determine if the variables "Schedule" and "Participants" were significant factors. The original effectiveness data set was modified to reduce the large variability between participants on the different schedules. This was done by excluding the data for the first three days of each

schedule to allow for circadian acclimatization. Variance was further reduced by removing the data of two participants who exhibited unusually large variance in their responses due to their studying for their watch station qualifications. A linear mixed-effects model was then used to discern schedule differences.

Hypothesis 1 was rejected. Although a significant difference existed between the modified experimental schedule and the original experimental schedule ($t_{52} = 2.49$, p = 0.0158, $\alpha = 0.05$), no significant difference existed between the normal submarine schedule and either the original experimental schedule ($t_{52} = -0.13$, p = 0.8944, $\alpha = 0.05$) or the modified experimental schedule ($t_{52} = 1.97$, p = 0.0537, $\alpha = 0.05$).

2. Hypothesis 2: Submariners Will Acquire More Sleep on the Experimental Schedule

Hypothesis 2 was tested in the same manner as hypothesis 1, with the exception that daily sleep minutes data was used in the linear mixed-effects model. In order to accentuate existing differences between Schedule 2 and Schedule 3, sleep data for 4 participants was removed because it became apparent that these participants received "kick outs" (refer to page 3) during the times Schedule 2 and 3 were implemented.

Hypothesis 2 was rejected. On average, the normal submarine schedule added 49.41 minutes of daily sleep as compared to the modified experimental schedule ($t_{48} = 4.48$, p<.0001, $\alpha = 0.05$) and 29.37 minutes as compared to the original experimental schedule ($t_{48} = 2.08$, p=0.0430, $\alpha = 0.05$). No significant difference existed between the modified and original experimental schedules ($t_{48} = 1.51$, p=0.1363, $\alpha = 0.05$).

3. Hypothesis 3: Submariners Will Notice Improvements in Their Own Performance While on the Experimental Schedule

Because of the discrepancy between the design of the exit survey and the manner in which it was implemented, the analyses to test hypotheses 3 and 4

were limited to descriptive statistics and correlations. Because of this issue, however, more weight was placed on written and verbal crew feedback. Correlations between exit survey responses confirmed the crew's written and verbal perception of the experimental schedules.

Hypothesis 3 was rejected. The exit survey demonstrated that only 15% of the respondents preferred one of the experimental schedules over the normal schedule, whereas 52% preferred the normal schedule. The other 33% were either indifferent or it was impossible to determine their preference. In addition, significant correlations ($r \geq 0.5$) demonstrated that those respondents who reported they did NOT like either experimental schedule also reported:

Less time for physical training (r=0.551, p= 0.000, $\alpha = 0.05$, N=130),

Less free time (r = 0.550, p = 0.000, $\alpha = 0.05$, N=130), and

Less time to perform collateral duties (r=0.533, p=0.004, $\alpha = 0.05$, N=130).

4. Hypothesis 4: The Experimental Watchstanding Schedule Will Be Compatible to an Operational Submarine Environment.

Hypothesis 4 was rejected. Significant but weaker correlations ($r \geq 0.3$) showed that respondents who reported they did NOT like either experimental schedule also reported more difficulty in:

Scheduling training (r=0.430, p = 0.000, $\alpha = 0.05$, N=112),

Scheduling maintenance (r=0.425, p = 0.000, $\alpha = 0.05$, N=114),

Performing administrative duties (r=0.352, p=0.000, $\alpha = 0.05$, N=116), and

Getting adequate rest (r=0.647, p = 0.000, $\alpha = 0.05$, N=130).

Direct feedback from the participating crew members (via written memorandums and a videotaped working group) confirmed that the experimental schedules did not provide the time needed to accomplish important tasks such as training, qualifications, drills, and perhaps most importantly, rest.

5. Summary

Results of this study demonstrated that there were no significant improvements in either cognitive effectiveness or daily sleep while on the new schedule. Additionally, a majority of the crew members did not like the new schedule. The new schedule attempted to compress watch periods together in order to widen periods for contiguous sleep. However, little collateral work was completed during the compressed watch period which meant unfinished work was carried over into the period set aside for sleep, defeating the intent of the new schedule's design. These results, taken together, demonstrated that the new schedule was not compatible with an operational submarine environment.

C. DETAILS OF THE DATA ANALYSIS

1. Effectiveness

a. Descriptive Analysis

Table 3 summarizes the daily FAST© effectiveness distribution for all participants on all schedules. The overall distribution in Figure 13 appears to be slightly left skewed.

Summary Statistics	Daily Effectiveness (%)
Min	23.76
1st Qu.	72.46
Mean	77.62
Median	79.29
3rd Qu.	84.95
Max	97.20
Std Dev.	10.32

Table 3. Summary Statistics of Average Daily Effectiveness Over All Participants and Schedules.

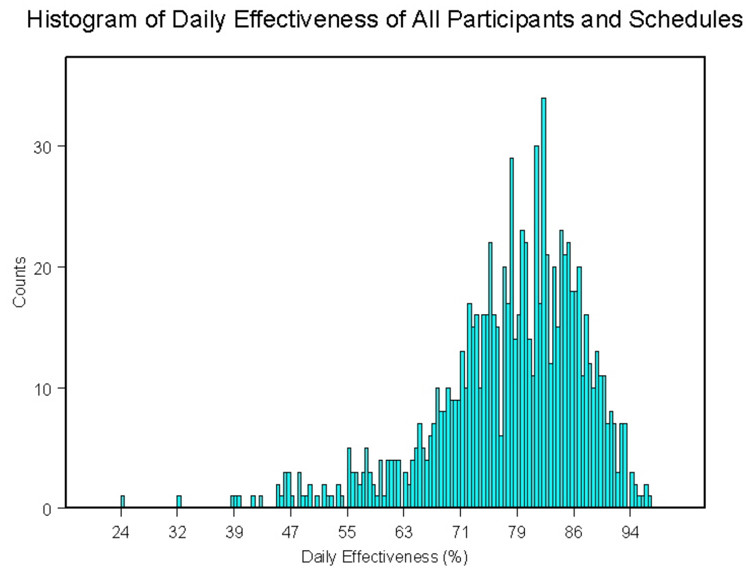

Figure 13. Histogram of Daily Effectiveness of All Participants and Schedules.

A boxplot illustrating the distribution of the average daily FAST© effectiveness for each participant is shown in Figure 14. Participants 7 and 21 have noticeably lower effectiveness than the rest of the sample. Further investigation revealed that these participants were both junior crew members pursuing qualifications for their respective watch stations.

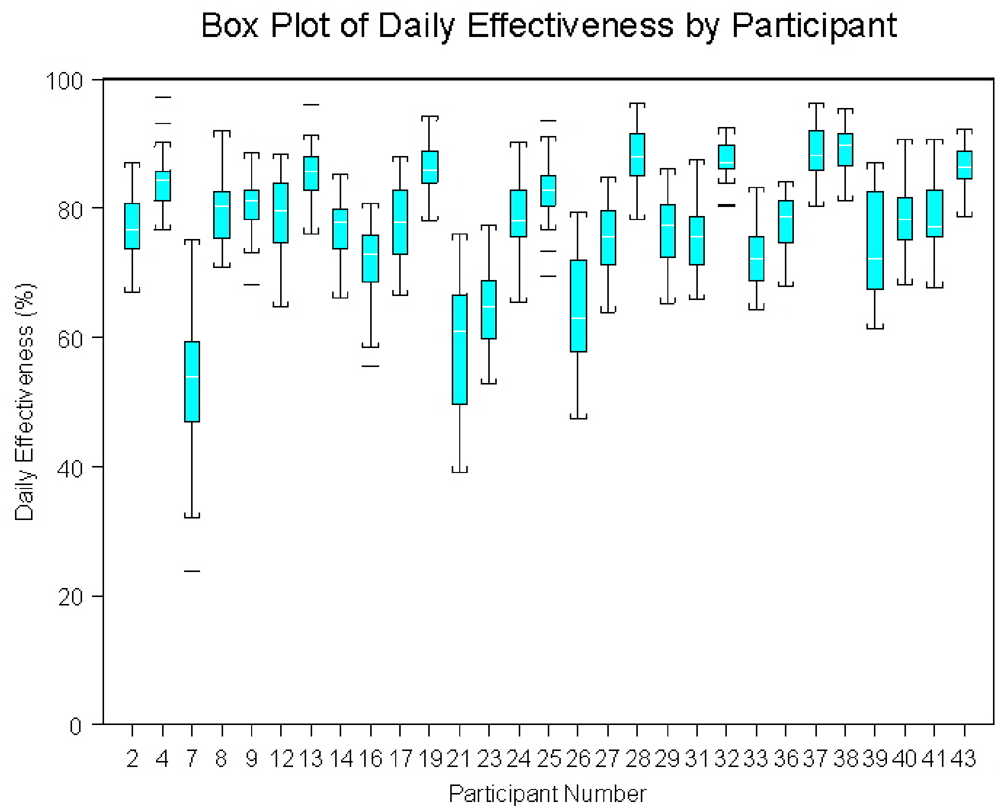

Figure 14. Box Plot of Daily Effectiveness by Participant.

Figure 15 illustrates the average daily predicted effectiveness of each participant by schedule. Average daily effectiveness ranges from 40% to 90%. No pattern readily emerges, except for the fact that Schedule 2 rarely appears to result in the highest daily effectiveness for any participant. Therefore, statistical model-fitting was used in an attempt to reveal any patterns or factors that contribute to differences in daily effectiveness. Model-fitting also made it possible to discern whether or not any schedule differences existed by conducting hypothesis tests on model parameters.

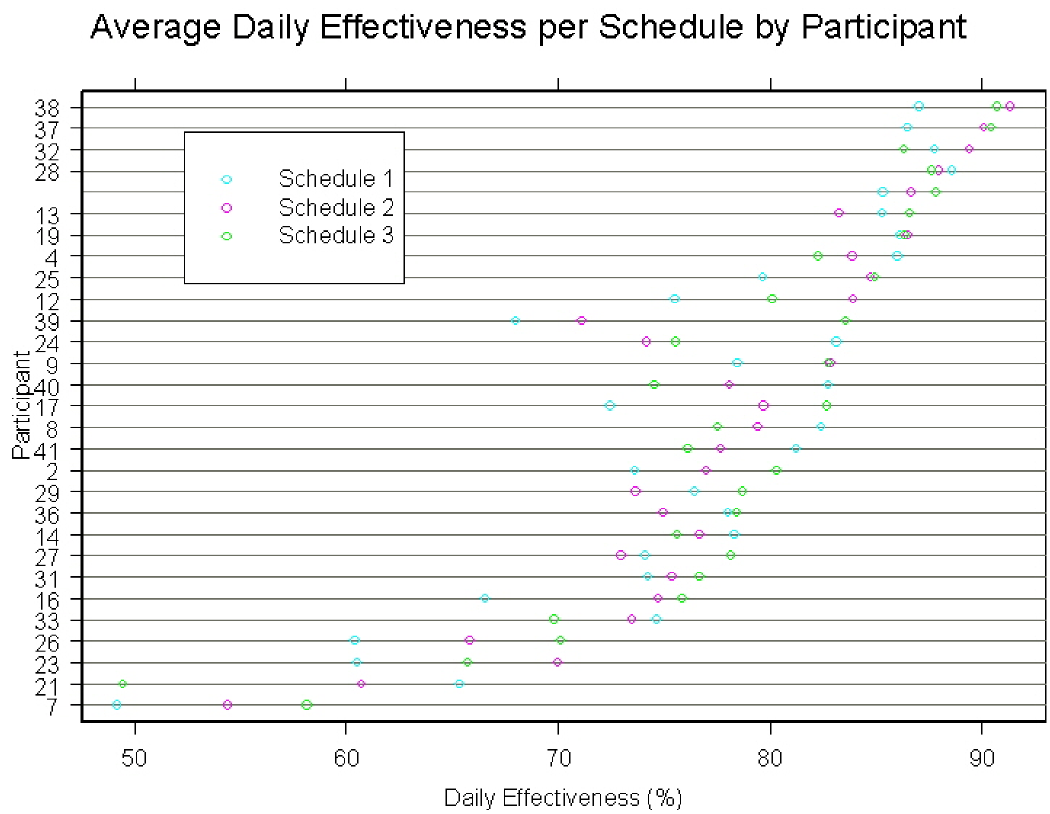

Figure 15. Average Daily Effectiveness per Schedule by Participant.

b. Model Fitting

(1) Data Exploration. In order to determine if there was a schedule acclimatization effect (refer to II.B.2), a linear multiple regression model was fitted using "Days" and "Participants" as categorical variables. The variable "Days" was simply the days of the experiment numbered consecutively. For example, Schedule 1 was implemented during days 1 through 14, Schedule 2 days 15 through 20, and Schedule 3 days 21 through 32. Due to the ordinal relationship between variables "Days" and "Schedule", they formed nonsingular columns within the data.

A plot was obtained using the daily predicted effectiveness from the model and using Day and Participant as factors. As shown in Figure 16, a noticeable downward trend existed among the first three or four days on each

schedule. This downward trend is to be expected since it takes a few days for the participants to adjust to each schedule. Thus, we excluded the first three days of data to allow for schedule acclimatization. Three days vice four was chosen in order to ensure enough data were available for Schedule 2 (there was originally only 6 days of data).

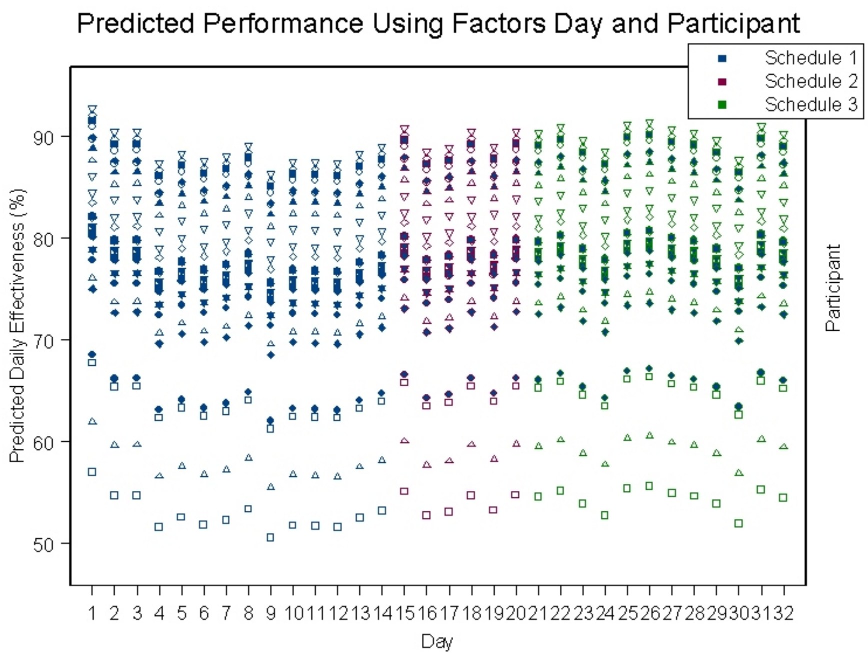

Figure 16. Predicted Performance Using Factors Day and Participant.

(2) Linear Mixed-Effects Model. After schedule acclimatization and extreme outliers were taken into account, a model was found in which both the variables Participant and Schedule were significant factors and there was a statistically significant difference between schedules. Unfortunately, we could not determine which schedule was best. This was due to the fact there was significant participant-schedule interaction. This interaction and the difficulties with the experimental design may have obscured systematic

differences between schedules. A new model must be used in order to separate participant-schedule interactions to look only at Schedule effects.

The linear mixed-effects model applies nicely to this experiment because it includes a repeated-measures design. This model was used to treat Schedule as a fixed effect, and the effects of Participants and the interaction between the two as random (Mathsoft, 2000). The fixed-effect variable Schedule is the repeated factor of interest. The variable Participant is a random effect because participants were randomly assigned, with departments proportionally represented. This model is described by Equation (1) below.

(1)

$$y_{ijk} = (\beta_0 + b_{0j} + b_{0ij}) + (\beta_{1i} + b_{1j} + b_{1ij})x_{ij} + \varepsilon_{ijk}$$

where:

i is the schedule index $\in \{1, 2, 3\}$,

j is the participant index $\in \{2, 4, 8, ..., 43\}$,

k is the day index $\in \{1, 2, 3, ..., 32\}$,

y_{ijk} are predicted cognitive effectiveness dependent variables for participant i on schedule j,

x_{ij} are binary predictor independent variables $\in \{1 \text{ if schedule } i \text{ and participant } j \text{ are of interest, } 0 \text{ o.w.}\}$,

β_0 is the intercept population parameter (fixed),

b_{0j} are participant intercept coefficients which are independent and identically (iid) distributed $N(0, \sigma^2_{b_{0j}})$ (random),

b_{0ij} are participant-schedule interaction intercept coefficients which are iid $N(0, \sigma^2_{b_{0ij}})$ (random),

β_{1i} are slope population parameters (fixed),

b_{1j} are participant slope coefficients which are iid $N(0, \sigma^2_{b_{1j}})$ (random),

b_{1ij} are participant-schedule interaction slope coefficients which are iid $N(0, \sigma^2_{b_{1ij}})$ (random),

ε_{ijk} are iid $N(0, \sigma^2)$ errors,

and $b_{01j}, \beta_{11}, b_{11j} = 0 \ \forall j$ forces schedule 1 as the reference schedule (for convenience).

Thus, we wish to test the hypothesis that there is no difference between schedules. In other words, $\beta_{11} = \beta_{12} = \beta_{13}$. We can now analyze fixed schedule effects separately from random participant effects.

Before continuing with the hypothesized model, it was necessary to perform diagnostics in order to test the performance of the model and validity of our assumptions. A plot of the model's residuals is presented in Figure 17. There do not appear to be signs of heteroskedasticity or unusually large variance (as had been the case when participants 7 and 21 were included). The residual plot confirms a good model fit.

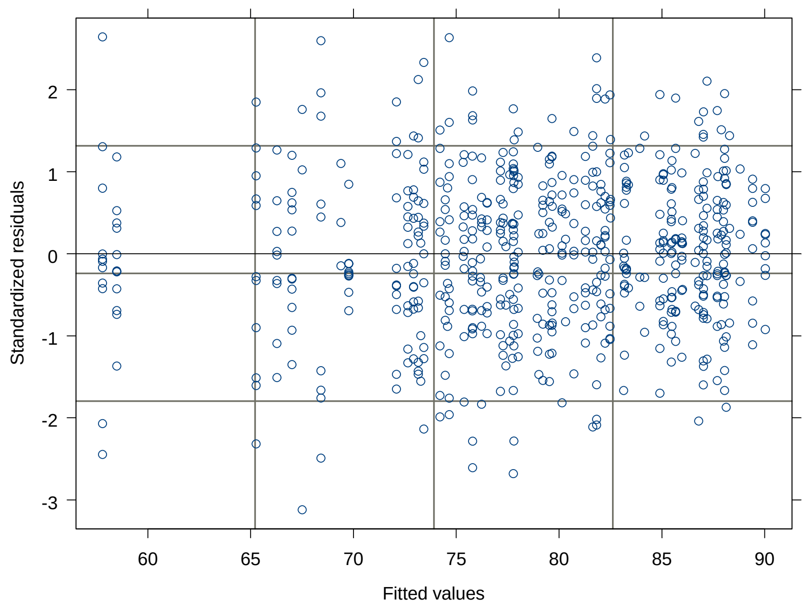

Figure 17. Residual Plot of Daily Effectiveness Linear Mixed-Effects Model.

Figure 18 is a standardized residual box plot used to investigate the model assumption $\varepsilon_{ijk} \sim N(0, \sigma^2)$. Residuals appear to be symmetrically distributed around zero with similar variability, with the exception of participant 26. Therefore, model diagnostics of the residuals indicate this model provides a good fit of the data.

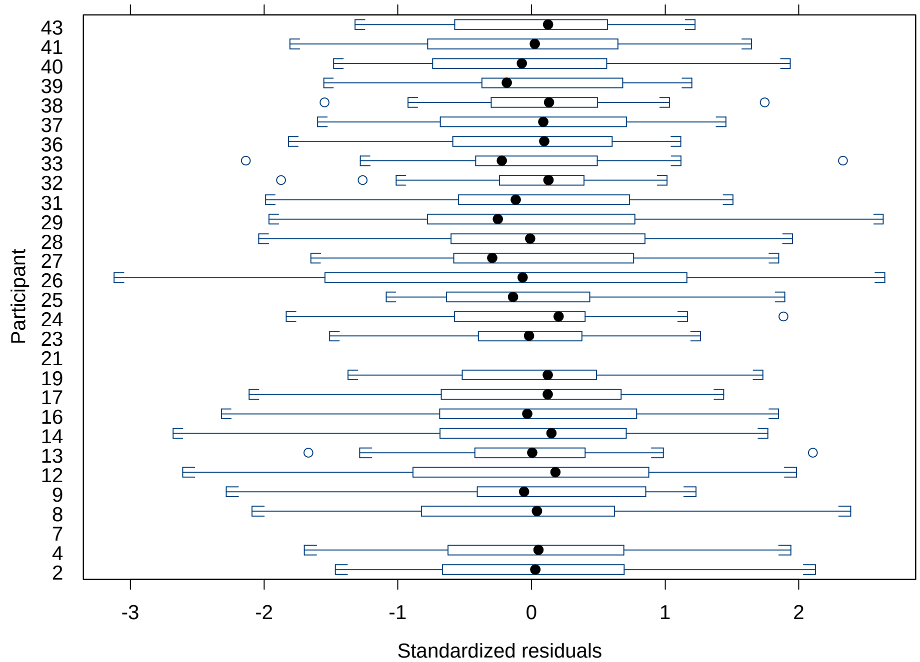

Figure 18. Standardized Residual Box Plot of Daily Effectiveness Linear Mixed-Effects Model.

Fitting the model using S-Plus 2000© with the modified data set obtained from the multiple linear regression, an ANOVA shows Schedule as a significant fixed effect ($F_{2,52} = 3.21$, p = 0.048, $\alpha = 0.05$). Having determined that there was a difference between schedules, a comparison of β_{1i}'s must be made to find *which* schedules are different.

Table 4 illustrates results from the model with Schedule 1 as the reference schedule (β_{11}=0). The t value for β_{12} (Schedule 2) is 2.49 ($t_{52} = 2.49$, p = 0.0158, $\alpha = 0.05$), which means it contributes 2.49% to daily effectiveness, on average, as compared to Schedule 1. Similarly, Schedule 3 adds 2.36% to daily effectiveness, on average, as compared to Schedule 1 ($t_{52} = 1.97$, p = 0.054, $\alpha = 0.05$).

	Value	Std.Error	DF	t-value	p-value
(Intercept)	77.66101	1.679669	540	46.23589	<.0001
Schedule2	2.48809	0.997334	52	2.49474	0.0158
Schedule3	2.36413	1.197722	52	1.97385	0.0537

Table 4. Linear Mixed-Effect Model Results for Daily Effectiveness with Schedule 1 as Reference Schedule.

In order to compare Schedules 2 and 3, the model was used again, except with Schedule 2 as the reference schedule. These results are posted in Table 5 below. As can be seen from this table, the difference between Schedule 2 and Schedule 3 was not statistically significant ($t_{52} = -0.13$, p = 0.8944, $\alpha = 0.05$).

	Value	Std.Error	DF	t-value	p-value
(Intercept)	80.14909	1.223475	540	65.50937	<.0001
Schedule3	-0.12396	0.929547	52	-0.13335	0.8944
Schedule1	-2.48809	0.997484	52	-2.49436	0.0158

Table 5. Linear Mixed-Effect Model Results for Daily Effectiveness with Schedule 2 as Reference Schedule.

2. Sleep Quantity

a. Descriptive Analysis

Table 6 summarizes the daily distribution of minutes of sleep for all participants and schedules. The overall distribution depicted in Figure 19 appears to be slightly skewed to the right, which indicates several instances of participants choosing to "sleep in" when given the opportunity.

Summary Statistics	Daily Sleep (minutes)
Min	0.0
1st Qu.	290.0
Mean	399.8
Median	385.5
3rd Qu.	490.0
Max	1032.0
Std Dev.	153.6

Table 6. Summary Statistics of Daily Sleep for All Participants and Schedules.

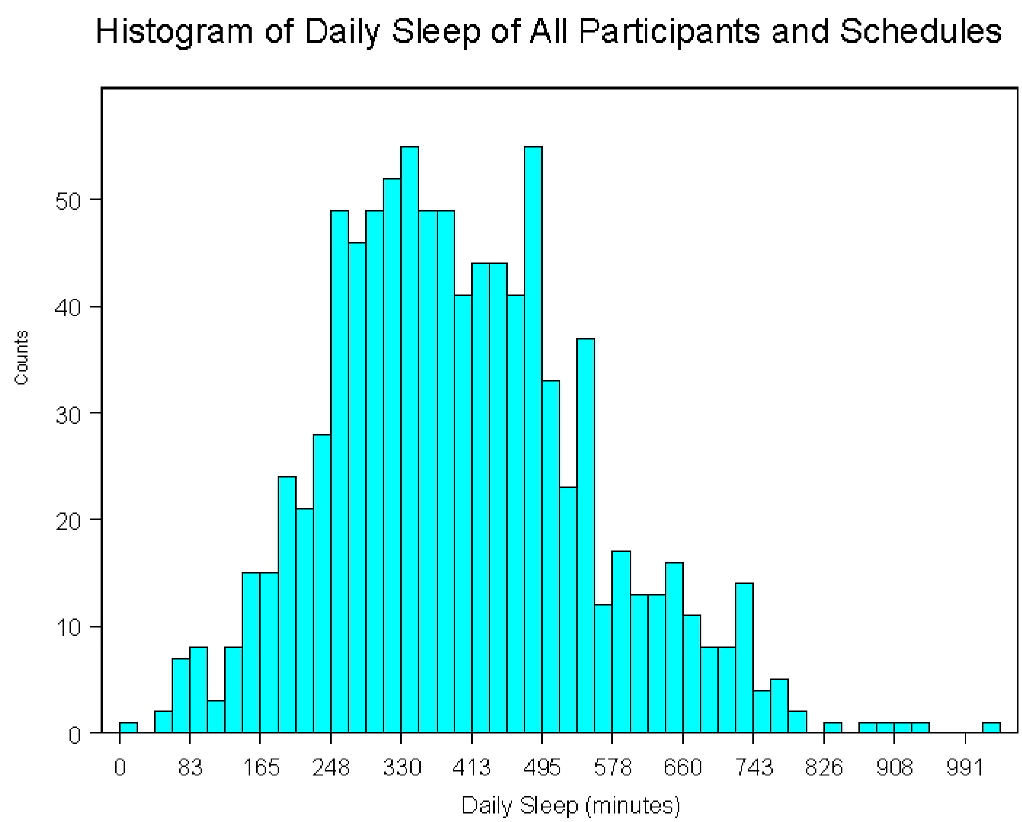

Figure 19. Histogram of Daily Sleep of All Participants and Schedules.

Statistics for daily sleep minutes (by schedule) can be seen in Table 7. Mean average daily sleep is greatest for the normal submarine watchstanding schedule. The relatively large standard deviation values indicate considerable variability exists in the data.

Daily Sleep Minutes:	Mean	Std.Dev.	Minimum	Maximum	N
Schedule 1	378.80	135.89	52	778	406
Schedule 2	399.71	181.07	47	929	174
Schedule 3	424.44	154.92	0	1032	348

Table 7. Summary Statistics of Daily Sleep Minutes by Schedule.

A plot which illustrates mean daily sleep minutes by schedule and participants is presented in Figure 20. As would be expected from the large standard deviations, average sleep varies widely by participants on a given schedule, much like average daily effectiveness in Figure 15. As large data variation between *schedules* is desired during data fitting, the small difference in daily sleep between Schedules 2 and 3 for participants 29, 9, 17, and 32 proved to be important during subsequent model fitting.

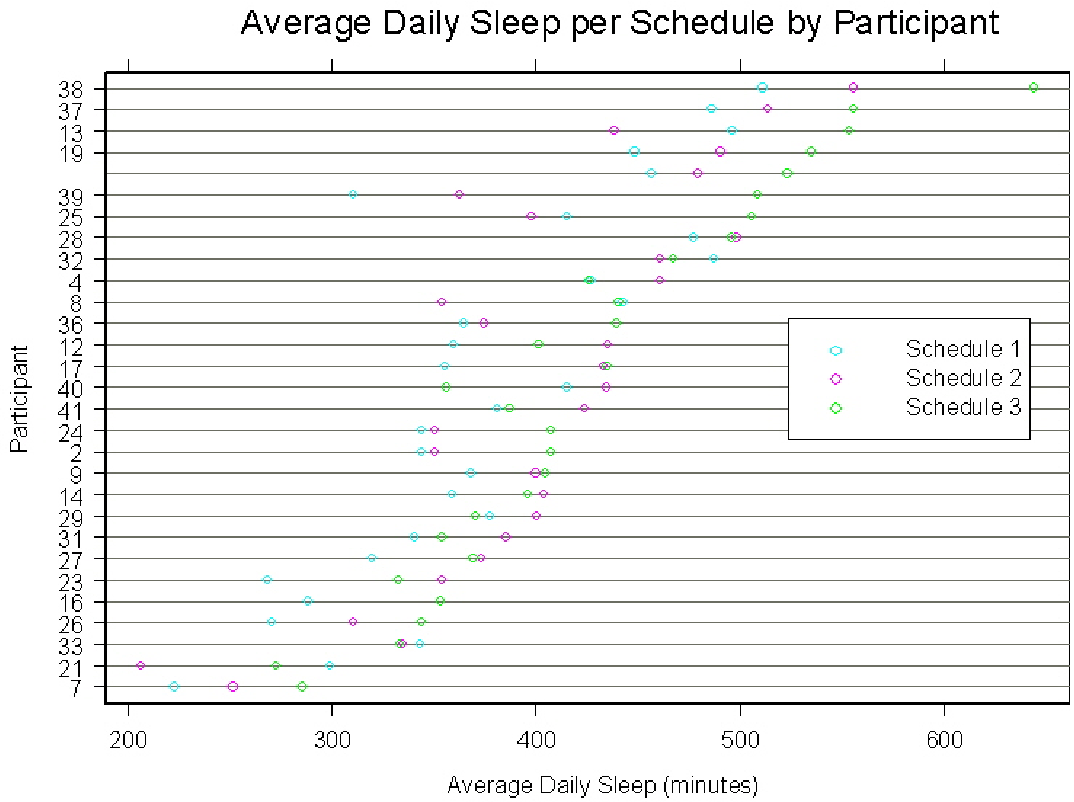

Figure 20. Average Daily Sleep per Schedule by Participant.

A boxplot illustrating the distribution of daily sleep for each participant can be seen in Figure 21. The data from Participants 7 and 28 stands out from the other participants. While most of the observations are between 200 and 500 minutes, there does not appear to be any significant anomalies within the sleep data distribution for this sample.

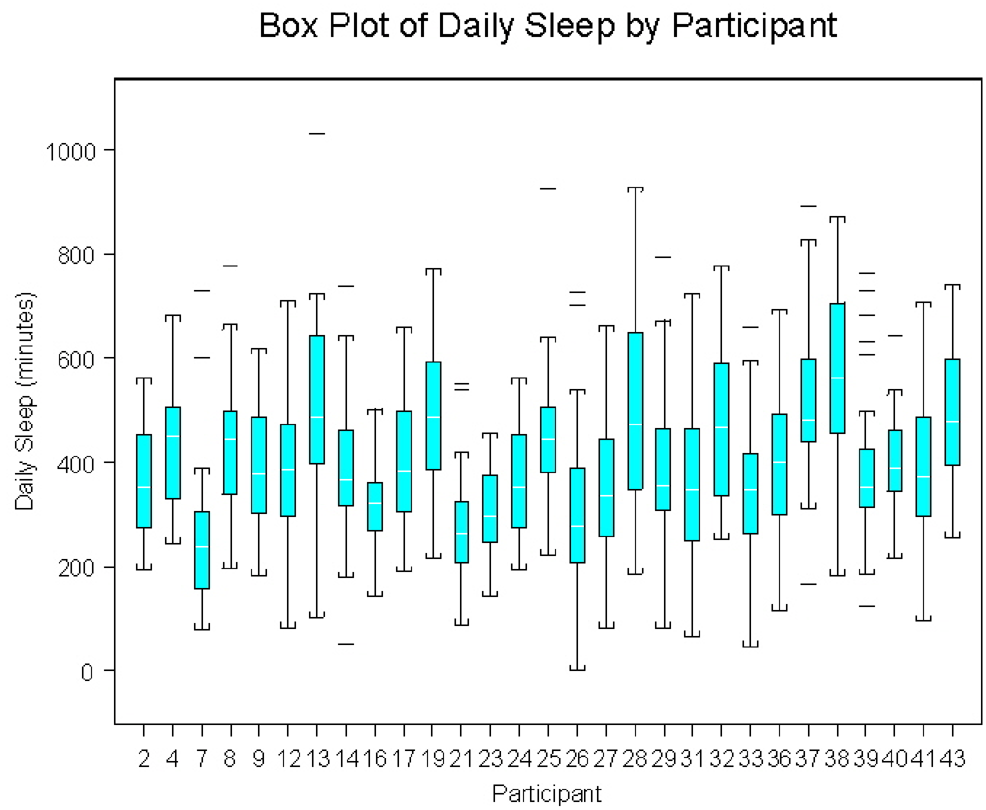

Figure 21. Box Plot of Daily Sleep by Participant.

b. Model Fitting

The linear mixed-effects model used in section 1.b(2) was applied to the sleep quantity data, except that Daily Sleep Minutes (smin) was now the dependent variable instead of Daily Effectiveness. The independent variables Schedule and Participant remained the same. To test the hypothesis that there were no differences between schedules (in other words, $\beta_{11} = \beta_{12} = \beta_{13}$), fixed Schedule effects can again be analyzed separately from random participant effects.

However, as before, we again perform diagnostics in order to test model performance and assumption validity. A plot of the model's residuals is shown in Figure 22. There do not appear to be any indications of

heteroskedasticity. Therefore, the residual plot helps confirm the goodness of model fit due to uniformly random appearance of $\varepsilon_{ijk} \sim N(0,\sigma^2)$.

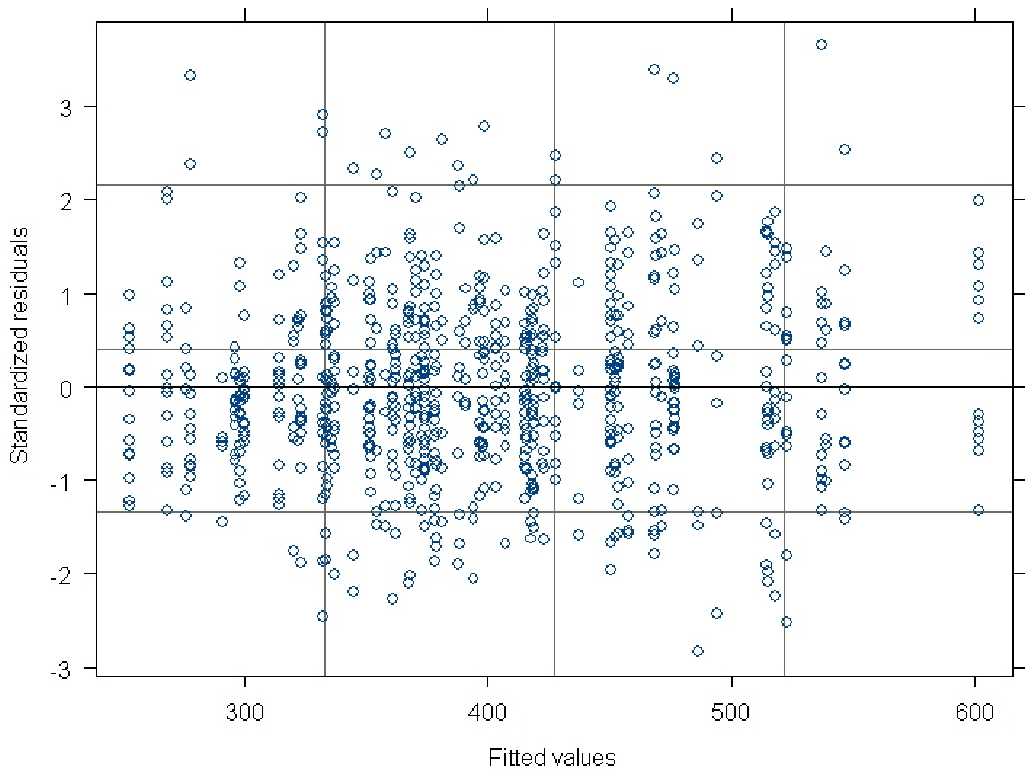

Figure 22. Residual Plot of Sleep Quantity Linear Mixed-Effects Model.

Figure 23 presents a standardized residual box plot useful in testing the model assumption that $\varepsilon_{ijk} \sim N(0,\sigma^2)$. The residuals appear to be symmetrically scattered around zero and display similar variability (with the possible exception of participant 28). As before, diagnostics of the residuals indicate this model provides a good fit of the data.

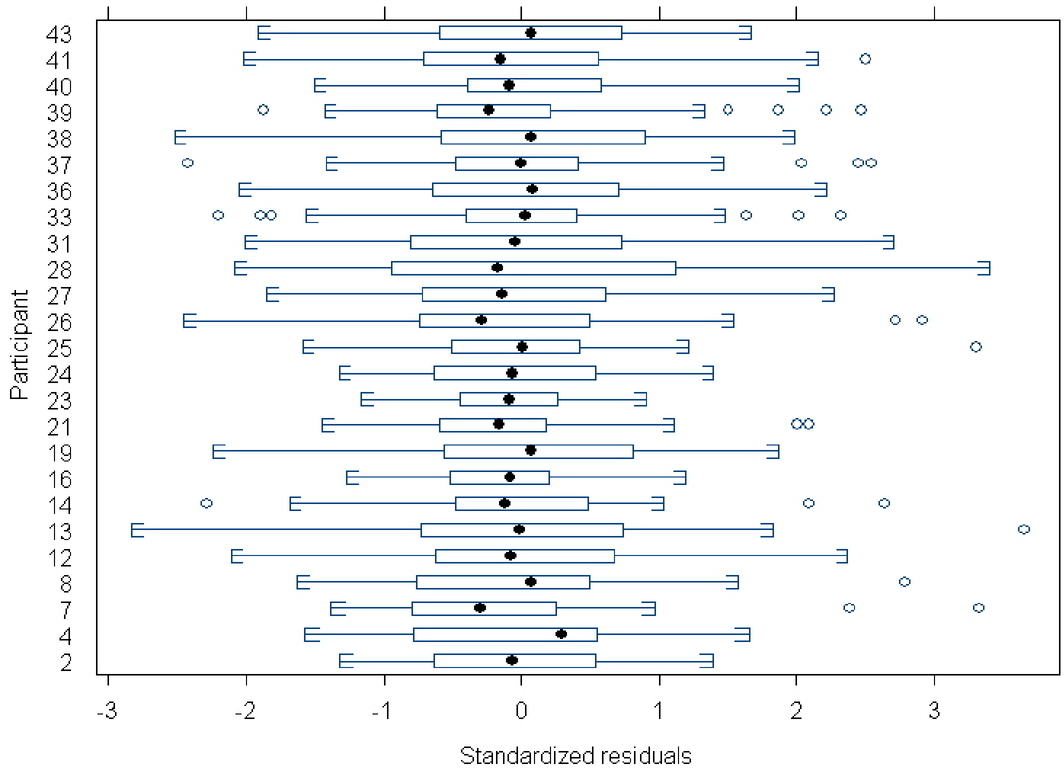

Figure 23. Standardized Residual Box Plot of Sleep Quantity Linear Mixed-Effects Model.

Fitting the model using S-Plus 2000© using the full data set for Daily Sleep Minutes (smin), an ANOVA shows Schedule as a significant fixed effect ($F_{2,56} = 10.27$, p = 0.0002, $\alpha = 0.05$). The null hypothesis was rejected, indicating that a difference exists between Schedules 1 and 3 ($t_{56} = 4.53$, p<.0001, $\alpha = 0.05$). However, it was not possible to reject the null hypothesis that no difference exists between Schedules 2 and 3 ($t_{56} = 1.93$, p=.0590, $\alpha = 0.05$), although a trend exists. As was done previously in fitting the model for daily effectiveness, a subset of the data was utilized, along with an explanation for doing so.

As mentioned before, Participants 9, 17, 29, and 32 had few differences in daily sleep for both Schedules 2 and 3. Upon closer inspection of

the actigraphy data for these participants, it became apparent that these participants received “kick outs” (see Chapter I.E) when Schedule 2 and 3 were being implemented. The modified three-section watch rotation these participants were in may help explain the small differences in schedules. Excluding these four participants from the data set and re-fitting the model, the ANOVA again shows Schedule as a significant fixed effect ($F_{2,48} = 10.03$, p = 0.0002, $\alpha = 0.05$). Table 8 illustrates the model results using Schedule 1 as the reference schedule ($\beta_{11} = 0$). No significant difference existed between Schedules 1 and 2. On the other hand, a significant difference existed between Schedules 1 and 3. Schedule 3 (the normal submarine schedule) *adds* 49.41 minutes to daily sleep, on average, as compared to Schedule 1 (the modified experimental schedule).

	Value	Std.Error	DF	t-value	p-value
(Intercept)	375.3400	15.97742	725	23.52319	<.0001
Schedule2	20.0400	13.22761	48	1.51501	0.1363
Schedule3	49.4067	11.03054	48	4.47908	<.0001

Table 8. Linear Mixed-Effect Model Results for Sleep Quantity with Schedule 1 as Reference Schedule.

In order to compare Schedules 2 and 3, the model is again fitted with Schedule 2 as the reference schedule. These results are presented in Table 9. As can be seen, Schedules 2 and 3 are now significantly different, indicating that Schedule 3 (the normal submarine schedule), *increases* daily sleep, on average, by 29.37 minutes as compared to Schedule 2 (the experimental schedule).

	Value	Std.Error	DF	t-value	p-value
(Intercept)	395.8800	17.79942	725	22.24118	<.0001
Schedule3	29.3667	14.12753	48	2.07868	0.0430
Schedule1	-20.0400	13.36939	48	-1.49895	0.1404

Table 9. Linear Mixed-Effect Model Results for Sleep Quantity with Schedule 2 as Reference Schedule.

3. Schedule Compatibility

As mentioned previously (Chapter III), the exit survey was originally designed to compare two schedules, not three. Because of this, any analysis of these surveys must be approached with caution, because respondents may not have understood which schedule the exit survey was referring to. For example, for the responses of 44 of the 134 participants, it was impossible to determine which schedule they were referring to when the exit survey was completed. For the remaining 90 respondents, there were approximately 24 surveys containing conflicting answers between the open-ended and the multiple choice responses. The resulting uncertainty regarding respondent intentions renders any interpretation of the cross tabulations meaningless. In addition, testing more than two schedules eliminates the possibility of using more powerful comparative statistical methods, such as paired t-tests, as was intended when the exit survey was designed. Consequently, in order to test hypothesis 1 and 2, we must rely on descriptive statistics, correlations, and direct feedback from the participating crew.

a. Descriptive Analysis

A majority of the crew was on a three section watch rotation (Table 10). This proportion was desirable because the experimental schedule was designed to assess those in a three section watch rotation.

Watch Rotation	Percentage of Respondents
Two Section	10%
Three Section	72%
Four Section	8%
More than Four Section	5%
Non-responses	5%

Table 10. Watch Rotation Distribution of Exit Survey Respondents.

The proportion of departments that participated is presented in Table 11 below (the sum of percentages exceeds 100% due to rounding).

Department	Percentage of Respondents
Engineering	39%
Weapons	28%
Navigation	17%
Supply	1%
Executive	4%
Officers	4%
Non-responses	8%

Table 11. Proportion of Departments Represented in the Exit Survey.

Open-ended responses were used to determine whether or not the respondent liked any of the experimental watchstanding schedules. In addition, surveys which exhibited apparent conflicts between open-ended and multiple choice responses were excluded when determining the proportion of respondents who preferred one of the experimental schedules over the normal

schedule (Table 12). With the 24 conflicting surveys excluded, a majority of the crew preferred the normal submarine schedule.

Preferred Schedule	Percentage of Respondents
Normal Schedule	52%
Experimental Schedule	15%
Indeterminate	33%

Table 12. Proportion of Schedule Preference, Excluding 24 Survey Conflicts.

b. Correlations

Pair-wise Pearson correlations between each exit survey response were computed using SPSS Version 12. Strong correlations ($r \geq 0.5$) demonstrate that those respondents who reported they did NOT like either experimental schedule also reported:

- Less time for physical training (r=0.551, p= 0.000, $\alpha = 0.05$, N=130),
- Less free time (r = 0.550, p = 0.000, $\alpha = 0.05$, N=130), and
- Less time to perform collateral duties (r=0.533, p=0.004, $\alpha = 0.05$, N=130).

In addition, other significant but weaker correlations ($r \geq 0.3$) show that respondents who reported they did NOT like either experimental schedule also reported more difficulty in:

- Scheduling training (r=0.430, p = 0.000, $\alpha = 0.05$, N=112),
- Scheduling maintenance (r=0.425, p = 0.000, $\alpha = 0.05$, N=114),
- Performing administrative duties (r=0.352, p=0.000, $\alpha = 0.05$, N=116), and
- Getting adequate rest (r=0.647, p = 0.000, $\alpha = 0.05$, N=130).

c. Direct Crew Input

Direct feedback from the crew was very helpful and offered insights into understanding how crews adapt to experimental schedules in an operational submarine environment. One important feedback instrument included a memorandum submitted by SKCM(SS) Gregg Weber at the end of the experiment.

(1) Chief of the Boat Memorandum. The crew's Chief of the Boat (COB), or the senior enlisted man onboard a submarine, submitted a memorandum dated 02 December 2003 to the Undersea Medical Officer, LT Chris Duplessis, who was involved in the experiment. This memorandum outlined some of the experimental schedule pitfalls and the experiences of crew members.

One major point introduced in the memorandum was the use of those personnel who are in the 24-hour off-watch period. The COB stated that he had to assign these personnel duties he would normally assign to those who had just finished standing watch (on a normal submarine schedule); otherwise known as "off-going assistance". These duties included ship cleanup, "de-rigging" the bridge (when the sub is on the surface getting ready to submerge), force protection watches, casualty response, and other major maintenance items including motor-generator cleaning, etc.

The COB also noticed effects in the following areas while on the experimental schedules:

- Workout areas were often empty
- Qualification progress halted
- Administrative work fell behind.

These observations were similar to those obtained in the correlational analysis. Also, individual qualifications are usually pursued during a crewmember's free time, leading one to speculate that the crew had less free time on the experimental schedules.

(2) Working Group Meeting. Another feedback session was a working group meeting that convened four months after the completion of the experiment. This meeting convened on 04 March 2004 at Naval Submarine Base, Bangor, Washington. Attendees included researchers from the Naval Submarine Medical Research Laboratory (NSMRL), the Naval Postgraduate School (NPS), and nine volunteer members from the USS HENRY M. JACKSON (SSBN 730 GOLD). Key personnel from the participating submarine included LCDR Kevin Kinslow, the ship's Executive Officer (XO), and the aforementioned COB, SKCM(SS) Gregg Weber.

Crew feedback, as taken from the minutes of the working group meeting, confirmed what has already been presented. The negative sentiments of the crew reflected their feelings that the experimental schedules did not provide the time needed to accomplish important tasks, including training, qualifications, drills, and perhaps most importantly, rest.

V. DISCUSSION AND RECOMMENDATIONS

A. DISCUSSION

1. Effectiveness

Although Figure 15 on page 47 gives a graphical display of average daily effectiveness for each participant, Table 13 (below) summarizes average daily effectiveness for all participants and days by schedule. As noted in the previous chapter, there is considerable variance in effectiveness results between participants and schedules. Regardless, it should be noted that the sample mean effectiveness for each schedule is near 77% which indicates substantial sleep deprivation. As can be seen from Figure 5 on page 18, a mean speed slightly above 80% (as measured by a PVT which roughly equates to predicted effectiveness) was achieved by the group restricted to 5 hours of nightly sleep. As was mentioned previously in II.D, chronic restriction of sleep to 6 hours or less per night produces cognitive performance deficits equivalent of up to 2 nights of total sleep deprivation (Van Dongen et al., 2003, Belenky et al., 2002).

	Schedule 1	Schedule 2	Schedule 3
Mean Daily Effectiveness (%)	76.83	77.96	78.39
Standard Deviation (%)	10.79	9.61	10.07
N	406	174	348

Table 13. Average Daily Effectiveness by Schedule.

Based upon the summary statistics above, submariner participants for this experiment appear, on average, to be sleep deprived even on their normal watchstanding schedule (using the 78% threshold the Air Force incorporates in scheduling flight hours via personal communication with J.C. Miller, March 4, 2004). It can be reasonably argued that standing watch on a submarine can be as mentally taxing as flying a jet aircraft. Although arduous training programs and strict discipline have given the U.S. submarine force an impeccable safety

record, it is apparent, in at least this case, that cognitive effectiveness has room for improvement.

Unfortunately, neither experimental schedule helped increase submariner cognitive effectiveness. Although Schedule 2 *increased* effectiveness by 0.12%, on average, schedule and participant interactions were non-significant. However, there may be schedules which can deliver similar or improved individual effectiveness, particularly compared to current fleet practices. A schedule which minimizes sleep deprivation would help to reduce degraded performance, work dissatisfaction, and chronic health problems.

2. Sleep Quantity

Table 7 on page 54 illustrates that the mean daily sleep was 424.4 minutes (slightly below 7.1 hours) on the normal schedule. This finding is consistent with those found by Kelly et al. (1996). Although being required to sustain operations on this amount of sleep may appear acceptable, it has been proven (at least experimentally) that even this amount of sleep can degrade cognitive performance (Belenky et al., 2002). Table 1 on page 8 shows that an operational schedule should ideally strive for an average of 8 hours of daily sleep. As the results from Table 7 illustrate, none of the schedules tested in this study consistently allowed the desired 8 hours of sleep, although the normal submarine schedule came closest. Thus, improvements in the current schedule need to be made to increase sleep quantity to recommended levels in order to minimize the consequences of sleep deprivation (as outlined in Chapter II.D).

3. Schedule Compatibility

The negative sentiments expressed by the crew suggest that the experimental schedules did not provide the time needed to accomplish important operational tasks (e.g., training, qualifications, and drills). Comments made in exit surveys indicated that it was difficult for the participants to adjust to the experimental schedules. However, a negative bias toward *any* schedule changes may have affected the crews' perceptions, given that more than one

experimental schedule was tested. Having the crew attempt to adapt to three different schedules in a relatively short period of time (32 days) may not have allowed a number of individuals to adapt to *any* schedule, and may have resulted in their negative comments.

Results of this study demonstrated that there were no significant improvements in either cognitive effectiveness or daily sleep while on the new schedule. Additionally, a majority of the crew members did not like the new schedule. The new schedule attempted to compress watch periods together in order to widen periods for contiguous sleep. However, little collateral work was completed during the compressed watch period which meant unfinished work was carried over into the period set aside for sleep, defeating the intention of the new schedule's design. These results, taken together, demonstrated that the new schedule was not compatible with an operational submarine environment.

B. RECOMMENDATIONS

Although this at-sea trial of the experimental schedules was unsuccessful in demonstrating improvements in submariner effectiveness and sleep hygiene, this study has contributed to the sleep literature by highlighting the intricately related operational constraints imposed on U.S. submariners and the effects of various watchstanding schedules. The contributions of this study will allow future schedules to be better suited to the operational submarine environment.

The results of this study illustrate that a need exists among the U.S. submarine force to improve upon current watchstanding schedules. A watchstanding schedule which allows for *both* better sleep hygiene *and* more time to complete required work should continue to be investigated. Such a schedule may increase tangible rewards for an individual, such as improved memory and cognitive effectiveness, but may also improve other, intangible factors, such as quality of life, morale, and the retention of qualified personnel.

The following recommendations were developed by members of the scientific and military communities present at a working group meeting conducted

on March 4th and 5th, 2004 (see Chapter IV.C.3.c(2)). This group concluded that the primary lessons learned from this study that should be implemented in the future include: experimental implementation, the need for sleep hygiene education, and several follow-on studies.

1. Experimental Implementation

As was mentioned previously, all participants in this study were members of a U.S. ballistic missile submarine (SSBN), and no data were obtained from crew members onboard a fast attack submarine (SSN). Due to the differences between missions and schedules for these two platforms, it is possible that different results might have occurred had this study taken place on a fast attack submarine. This should be considered when developing and testing alternative watchstanding schedules.

In order to alleviate possible confusion, future research should ensure that training, drills, and other scheduling needs are worked out in advance *prior* to the boat getting underway. Bias in the crew's perception of the experimental schedule would be minimized, as there would be fewer unexpected alterations or modifications to the experimental schedule.

The harsh working environment aboard a submarine poses a risk for delicate electronic equipment and several WAMs failed during the experiment. Twelve of the 41 WAMs experienced a failure of some kind, which, in turn, limited the data available for analysis. Future studies should assume the loss of a number of WAMs, and should plan for this attrition by oversampling.

As was mentioned in III.D.2, exit survey question phrasing was confusing for some individuals. Future research should reword the exit survey such that it would only have to be taken once. The exit survey wording should ensure that respondents are not confused about the match between schedules and particular questions.

2. Education

Fatigue management should be incorporated into the education that the submarine community receives in both officer and enlisted submarine schools. This training should make officers and enlisted aware of the causes, symptoms, and dangers of a sleep-deprived crew. Some ways a supervisor can effectively manage fatigue among personnel are outlined below by Chapman (2001, pp. 23-24):

- Allow time for adequate sleep prior to coming on watch
- Avoid assigning personnel who are in need of sleep non-urgent tasks during off-watch periods
- Allow frequent breaks and task rotation to alleviate strain and boredom. Monitoring tasks should be no more than four hours in length to sustain operator vigilance
- Encourage personnel to utilize off-watch periods to obtain adequate sleep
- Lead by example.

3. Suggested Follow-on Studies

a. Critical Watchstanding Task and Risk Factor Analysis

As mentioned in the *Minutes of the At-Sea Watchstanding Trials Working Group Meeting* (Duplessis, 2004), a task and risk factor analysis of various watch stations should be undertaken. The goal of this research would be to identify the critical watch stations where errors could cause or lead to catastrophic outcomes. Focused interventions, such as establishing recommended guidelines for minimum sleep requirements (Chapman, 2001) or rating-specific schedules, could then be implemented. In addition to focused interventions, performing a task analysis could also suggest recommendations

on manning requirements *prior to* a submarine getting underway (e.g., prohibiting two-section watch rotations in identified critical positions).

b. Testing Other Experimental Schedules

Three alternative watch schedules are currently being considered for future testing, including: fixed, 8-hour schedule; a compensated 6-hour "dogged" schedule; and a fixed, 6-hour "dogged" schedule (Duplessis, 2004, p. A-1). A "dogged" schedule involves splitting difficult watch periods between two or more watch sections in order to minimize fatigue effects and maintain alertness on a particular watch section. If a future laboratory-derived watch schedule is obtained, it should be presented to the fleet for a review of its operational feasibility *prior* to conducting at-sea trials with an operational submarine.

APPENDIX A DEMOGRAPHIC SURVEY

Please complete the following survey to the best of your ability. This survey will be used for research conducted by the Naval Submarine Medical Research Laboratory and all data contained herein will be kept confidential.

What is your participant number?

What department are you assigned to?

What division are you assigned to?

Are you currently on a watchbill?

- Yes
- No

If so, what is the average length of your watch? (hours)

What is your rating?

Do you have a nuclear designator?

- Yes
- No

What is your rank?

What is your age?

What is your height? (in inches)

What is your weight? (in pounds)

During the past three days, how much sleep did you average per day? (hours)

On average while underway, how many naps do you take per day?

List any medications (either over-the-counter or prescription) that you are currently taking.

On an average day while underway, how many caffeinated beverages do you consume?

On an average day while underway, how many times do you consume a cigarette or product containing nicotine (dip, patches, etc.)?

Thank you for completing this survey! Please review your entries for accuracy and then click here to submit your answers.

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APPENDIX B EXIT SURVEY

Please complete the following survey to the best of your ability. Answer the questions from what you can remember this past week. This survey will be used for research conducted by the Naval Submarine Medical Research Laboratory and all data contained herein will be kept confidential.

What is your participant number?

What kind of watch rotation were you on last week?

- ○ not on watchbill or other
- ○ port/starboard
- ○ three section
- ○ four section
- ○ more than four section

In an average day last week, about how many 12-ounce caffeinated beverages did you consume?

Please list any medications you have taken within the last week (prescription or over-the-counter).

In an average day last week, about how many cigarettes or other products that contain nicotine (number of dips, patches, etc.) did you consume?

How many hours of sleep per night do you personally think you need to function at your best? (hours)

Taking into account your current watch rotation, how many hours of sleep would you like to get before watch? (hours)

Have you incurred EMI and/or extra duty during the last week?

- ☐ Yes
- ☐ No

If so, how many hours?

What do you perceive crew morale to be?

Very High	High	Somewhat High	Fair	Somewhat Poor	Poor	Very Poor
○	○	○	○	○	○	○

On average, how many hours of uninterrupted sleep did you get each day last week? (hours)

On average, how many hours of total sleep did you get prior to standing each watch within the last week? (hours)

About how many times in the last week did you have difficulty in falling sleep?

On average, how long did it take you to fall asleep? (In minutes)

Within the last week, about how often after falling asleep did you wake up early and couldn't get back to sleep again? (number of times)

How easy was it for you to wake up to the General Alarm this past week? (given you can hear it from your location)

Very Easy	Easy	Somewhat Easy	Average	Somewhat Difficult	Difficult	Very Difficult
○	○	○	○	○	○	○

How did you physically feel after watch on most occasions this past week?

Very Energetic	Energetic	Somewhat Energetic	OK	Somewhat Drained	Drained	Completely Drained
○	○	○	○	○	○	○

What percentage of the time last week did you:

	100% (Always)	90%	80%	70%	60%	50% (Sometimes	40%	30%	20%	10%	0% (Never)
a. feel so tired that you can't concentrate on watch?	○	○	○	○	○	○	○	○	○	○	○
b. have difficulty staying awake while on watch?	○	○	○	○	○	○	○	○	○	○	○
c. experience mood changes during watch?	○	○	○	○	○	○	○	○	○	○	○
d. notice mood changes of others during watch?	○	○	○	○	○	○	○	○	○	○	○
e. have difficulty waking up or getting out of bed?	○	○	○	○	○	○	○	○	○	○	○
f. still feel tired 30 minutes after you get out of bed?	○	○	○	○	○	○	○	○	○	○	○

On average, how many hours per day do you spend on watch, training, and/or drilling?

The current manning can support three sections underway for my watchstation(s).

- ☐ True
- ☐ False
- ☐ Not sure

The current manning can support four sections underway for my watchstation(s).

- ☐ True
- ☐ False
- ☐ Not sure

For the current watch rotation, how easy is it to:

	Don't know	Very Easy	Easy	Somewhat Easy	Average	Somewhat Difficult	Difficult	Very Difficult
a. schedule training?	○	○	○	○	○	○	○	○
b. schedule maintenance?	○	○	○	○	○	○	○	○
c. accomplish administrative tasks?	○	○	○	○	○	○	○	○
d. schedule or participate in drills?	○	○	○	○	○	○	○	○

For your watch rotation this past week, indicate how much you agree or disagree with the following statements:

	Strongly Agree	Agree	Somewhat Agree	Indifferent	Somewhat Disagree	Disagree	Stongly Disagree
a. I am satisfied with the amount of time I had to conduct physical training.	○	○	○	○	○	○	○
b. I am satisfied with the amount of personal or "free" time.	○	○	○	○	○	○	○
c. I had enough time to perform collateral duties.	○	○	○	○	○	○	○
d. I had enough time to work on administrative tasks.	○	○	○	○	○	○	○
e. I got enough sleep to perform my job to the best of my ability.	○	○	○	○	○	○	○
f. I was effective and alert after watch.	○	○	○	○	○	○	○
g. I got adequate rest.	○	○	○	○	○	○	○
h. Overall, I am satisfied with my current watch schedule.	○	○	○	○	○	○	○

What do you like about the current watchstanding routine?

What would you like to change about the current watchstanding routine?

Thank you for completing this survey! Please review your entries for accuracy and then click this button to submit your answers.

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